METAL PROGRESS

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The sketch on the cover was made about 450 years ago by Leonardo da Vinci, and represents an arsenal. Need we say that the design is modern?

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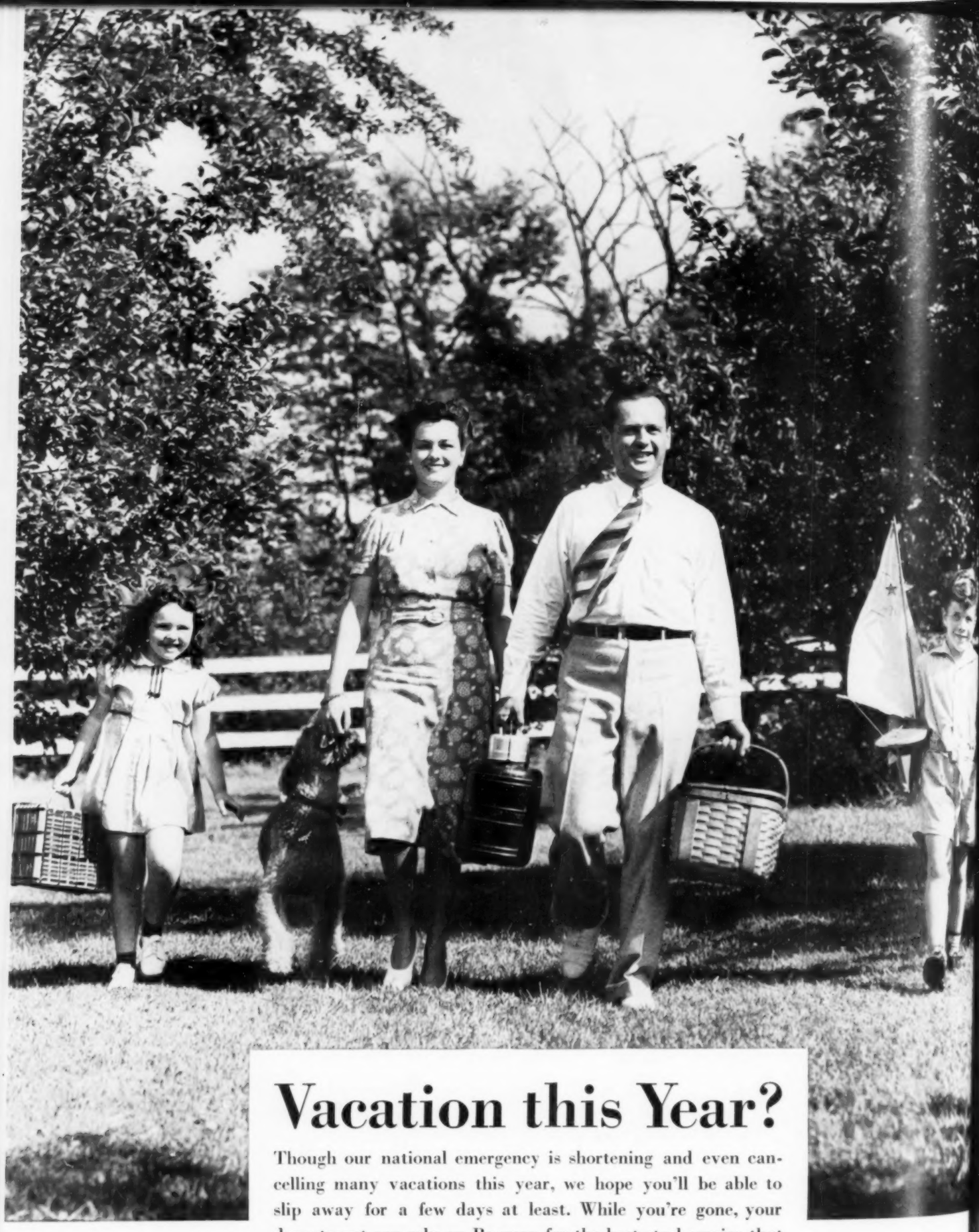
Published monthly and copyrighted, 1941, by American Society for Metals, 7301 Euclid Ave., Cleveland, Ohio. Subscriptions $5 a year in U. S. and Canada (foreign, $7.50); current copies $1; special reference issues $2. Entered as second-class matter, Feb. 7, 1921, at the post office at Cleveland, under the Act of March 3, 1879. . . . The American Society for Metals is not responsible for statements or opinions printed in this publication. The Editor is sponsor for unsigned and staff articles. . . . Notices of new address should always be accompanied by the old one.

AUGUST, 1941 VOLUME 40 NUMBER 2



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Though our national emergency is shortening and even cancelling many vacations this year, we hope you'll be able to slip away for a few days at least. While you're gone, your department can rely on Ryerson for the best steel-service that present-day circumstances will permit. In times like these, we are naturally out of many sizes but we still have a fair stock and service continues without interruption. So make the best of your days off . . . Relax! Build yourself up for the hard winter months ahead. Ryerson will help hold the fort.

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DEEP DRAWING STEEL

(low carbon)

By Lorenz W. Heise
A. O. Smith Corp.
Milwaukee, Wis.

"DEEP DRAWING STEEL" is an extremely broad subject, even after narrowing it to illustrations of a few of the practical aspects of the cold drawing of low carbon steels. This is not to belittle the importance of carbon steels for hot forming, or alloy steels for either hot or cold work, for their use is growing year by year.

Possibly, the first "drawing operations" on iron or steel were performed some thousands of years ago on iron similar in structure to modern wrought iron, pounded into the form of a plate, a blade, a crude tool of some kind, or an object of warfare. We may consider a plate so formed very crude when compared to the beautiful sheets and plates which are today being produced by our steel mills, but when we stop to realize the developments which have taken place within the past century (and are still taking place) along the lines of analysis control, metallurgical structure, and surface finishes, we can only imagine that a few more decades of progress may bring super steel and finishes to dwarf any developments within our time.

In this present discussion we shall assume that the steel mills are furnishing only the best quality of steel known for the intended use, and that the manufacturer needs only to indicate his requirements and the steel will be produced accordingly.

In making a study of the deep drawing problems arising in the cold working of steel in our own plant, I find it convenient to divide them into three general groups, as follows:

1. *Progressive drawing* such as spinning or hammering in which only a relatively small area of the part is affected at any one time, but by continued application of similar forces the ultimate desired section is obtained.

2. *Consummate drawing* such as forming, folding, or molding in which a large area of the part is affected at one time.

3. *Centralized drawing* such as cupping, extruding, or drifting in which a relatively small area of the part is affected in one quick operation.

Most production parts will not be confined purely to any one type, but will consist of a combination of the types. However, the material requirements will obviously be governed to a great extent by the work which must be done on the most difficult portion of the piece.

A few pictures have been prepared to illustrate some of these drawing operations much more effectively than they can be described in words (pages 164 and 165).

Figure 1 illustrates the progressive type of drawing. At the left is a spun part of light metal; the others are some hand-formed frame parts of heavier steel.

Hand-formed parts are made (in A. O. Smith Corp.'s plant) chiefly for sample frames to be used by automobile makers for new models and test cars. They also serve a very practical purpose to us in our tool design, in determining the limits of radii and other details.

Spinning is used to a very limited extent in our plant, and I believe this is generally true. It is applied chiefly to relatively simple circular parts where production requirements do not warrant the tool cost for drawn parts, or where the mouth is contracted so an inner forming tool would have to be collapsible to be withdrawn after use.

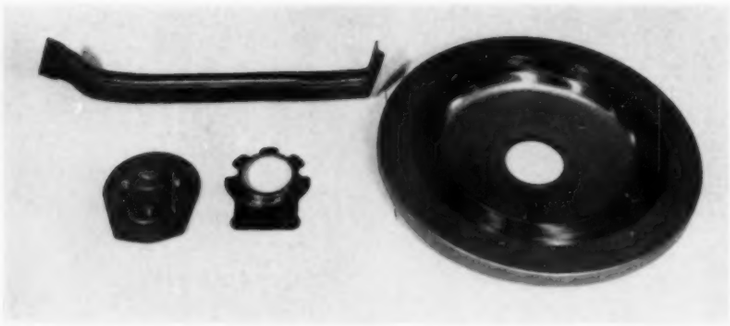
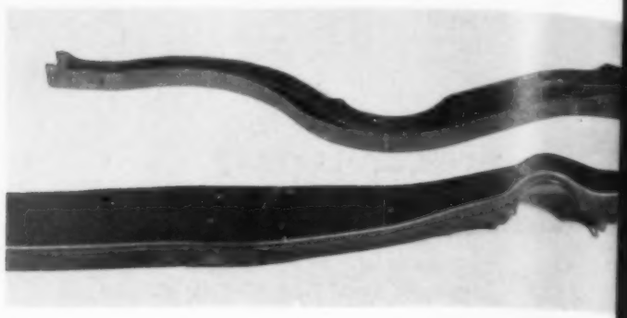


Fig. 1, above — Saddle for Automobile Gas Tank, Upper Plate and Lower Plate for Central Arm, and a Spun Disk. The three at left are hand-formed of thicker metal than the disk, but all are examples of "progressive" drawing

Fig. 2, below — An Example of "Consummate" Drawing Is T Side Bar of an Automobile Frame. The "kickup" at the en the most difficult part involving much forming and some fold



The consummate type of drawing is shown in Fig. 2, a photograph of the front and rear ends of an automotive side bar with the "kickup" (which is generally the most difficult part of this bar to draw). Much forming and some folding is done on this single piece.

Figure 3 also illustrates the consummate type of drawing, which applies forming, folding, and molding to make an automotive front cross bar. The depth of the draw is not well illustrated, but the general extent can be noted by comparison with the blank.

Tie plate and spring seat shown in upper part of Fig. 4 are relatively simple draws, whereas the automotive rear cross bar shown in two different positions is most difficult (although it looks simple), due to the combination of a deep draw and a sharp radius which must be maintained on the draw edges.

Consummate drawing of heavier parts is next shown in Fig. 5: Hot water tank heads, for gas or electrically heated boilers, as well as some frame parts. The latter are a truck helper bracket and an automotive front bar reinforcement. None of these parts are trouble makers.

Figure 6 illustrates several applications of the third general type, or centralized forming. (It may be erroneously called "extrusion".) The small bushing shown at upper left is made of ¼-in. stock, blanked out into an octagonal slug and then drawn ("extruded") to a stubby bushing, ⅛ in. thick in the neck wall, for ultimate assembly to an automotive control arm which has in itself already been made by centralized forming. The clutch pedal arm is another example of similar work on heavy stock; the large tapered blank is first formed and punched as shown in the center, and then a further extrusion is pushed up at the hole in the big end.

Extra attention to the drawing compounds is required on this type of work to avoid rejects.

Combination of consummate drawing and centralized drawing is shown in Fig. 7 illustrating the automotive lower control arm assembly and parts. Manufacture of these parts requires

Fig. 3, below — Blank and Front Cross Bar for Auto Frame Made Therefrom. A very deep draw and a good example of "consummate" drawing

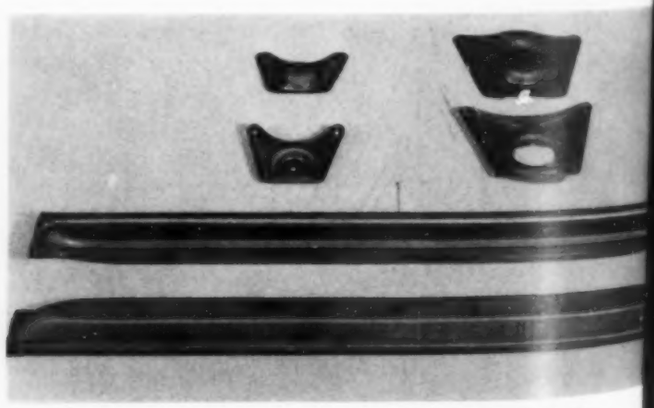


Fig. 4, above — The Cross Bar Shown Below the Tie Plate and Spring Seat Is Much More Difficult to Make, With Its Deep Draw and Sharp Radius Bends

Fig. 5, below — No Trouble Makers These. Hot water tank head, truck helper bracket and frame bar reinforcement — all drawn from relatively heavy gage

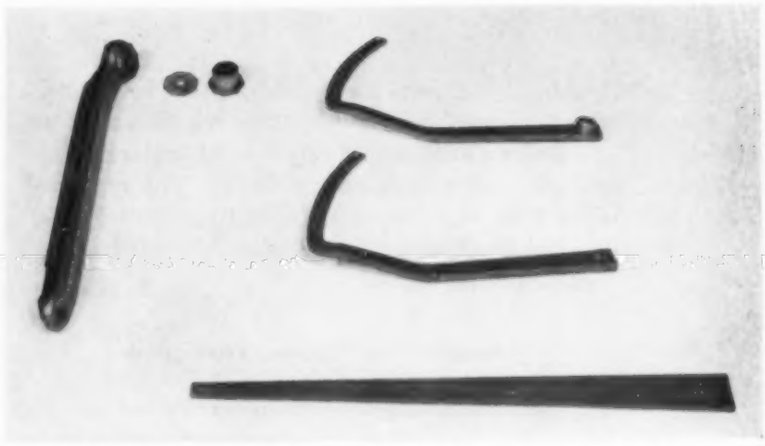


Fig. 6, above — Bushings With Relatively Thin Walls Are Formed ("Extruded") Starting With Flat Stock Having a Central Hole. These are examples of "centralized" forming

some real practical tool engineering, as the control arm is formed from the blank in a single operation with an extrusion on each end.

An assembly of an upper control arm, shown in Fig. 8, is very similar to the arm previously shown in Fig. 7, but somewhat more intricate in shape.

Now, what material is used in the production of parts as shown? It is no super-metal, rare and expensive. In fact, most low carbon steels for deep drawing purposes would conform to S.A.E. 1010 in chemical analysis. (Carbon 0.05 to 0.15%, manganese 0.30 to 0.60%, phosphorus 0.045% max., and sulphur 0.055% max.) It is quite possible to draw harder steels; in fact, under certain circumstances where shape and tooling are favorable, carbons may run up to 0.25% with manganese up to 0.60%.

Experience in the deep drawing field indicates that it is sometimes difficult to estimate the exact grade of steel for any specific part. Naturally, production shops are interested in keeping costs at a minimum, which means that operations must be combined or eliminated wherever possible. In addition to extra tool engineering, this means that more is expected from the steel in the revised set-up.

When these changes and developments are made, the first step is to determine whether or not the customer would approve of a slight change in design to obtain larger radii or make some other change to favor a draw. After this consent has been given, close contact and cooperation with the steel mills is essential to develop maximum production. Short production runs are very effective in questionable cases; a higher grade material may be ordered for initial runs with a close follow-up by production department, tool engineering, inspection, and steel mill's representatives.

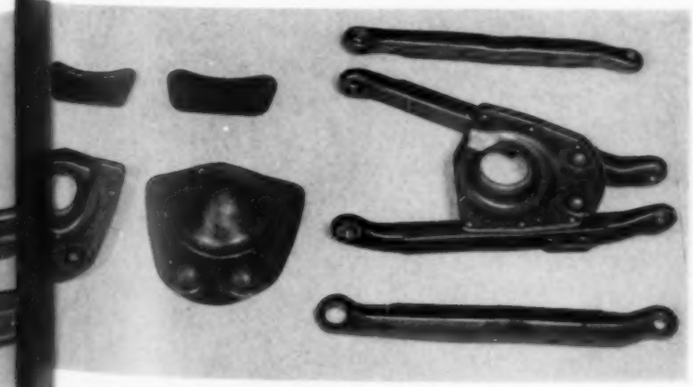
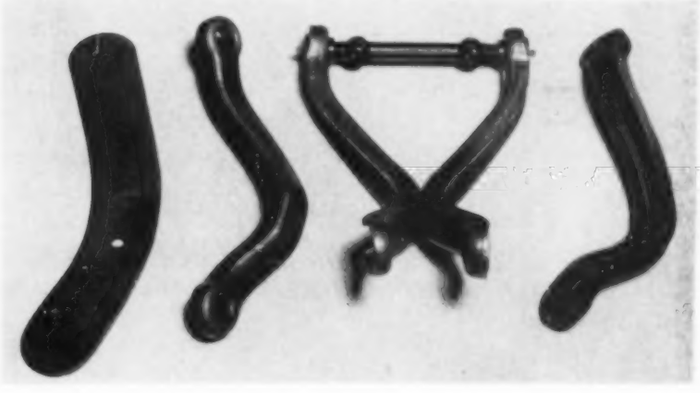


Fig. 7, above — Automotive Lower Control Arm Parts and Assembly. A difficult job, combining consummate and centralized forming. Note the bushings thrown up at each end of the arms; all done from the blank in a single operation

Fig. 8, below — Upper Control Arm Somewhat More Intricate in Shape Than Fig. 7



Eventually a less costly steel may be found adaptable to the new operating schedule.

Rolling mills inevitably leave the steel sheet and plate in a stressed condition. The method of cooling or subsequent heat treatment has a decided bearing on the ultimate drawing qualities of the material.

Acceptable Microstructures

One cannot by any means cover the structural phases of deep drawing steels in a short article, but inasmuch as the structure has such a vital influence on the workability, I shall present three micrographs of the center portions or core of rimmed steel which we have found to be suitable for our work. All were taken at 100 magnifications after a 2% nital etch. You will note that the grains are nicely equi-axed. Material showing elongated grains due to cold rolling can seldom do such work as illustrated on the preceding pages.

The first micro (Fig. 9) shows as-rolled steel, possibly finished "on the cold side" (slightly above the critical temperature). This has a fine grain, A.S.T.M. No. 8 or 9, approximately 196 per sq.in. at this magnification. Such a steel is suitable for any simple draw, but not for extrusion.

Normalized steel (medium grain, A.S.T.M. No. 6 or 7, approximately 48 grains per sq.in.) is shown in Fig. 10. This structure is ideal for most deep-drawn parts, including extrusion of stock under 0.200 in.

The last micro shows normalized or annealed steel. It has a coarse grain, A.S.T.M. No. 5, with approximately 18 grains per sq.in. at this magnification. The steel was possibly finished on the hot side, above the critical temperature, or has been annealed. It is ideal for extruding stock, 0.200 to 0.400 in. thick.

We, at the A. O. Smith Corp., do not specify grain size in ordering steel for deep drawing, but work very closely with steel company representatives so that they in turn can convey the requirements to the men in control of mill production.

Supposing now we have ordered materials to the best of our knowledge for the use intended and still encounter drawing difficulties, wherein lies the trouble?

Experience tells us that one of three factors must be involved in the breakage. If any two of these items are found to be correct, the trouble inevitably lies in the third. Hence, if the steel is found to be correct and the tools are found to be correct, the trouble must be in the set-up. The method of judging or determining which item is responsible is not always a simple matter. When the problem arises we immediately begin our check, sometimes one item at a time, but under stress of production all three must be tackled at once until the offender has been segregated and corrected.

In summing up the deep drawing problem, I believe that technicalities are of major importance. However, the most essential element of the entire scheme of production is a serious spirit of willing cooperation between the steel producer and his manufacturing customer, and the same spirit prevailing within each of the organizations.

Center Portion or Core of Rimmed Steels, Suitable for Deep Drawing, Magnified 100 Diameters, Nital Etched

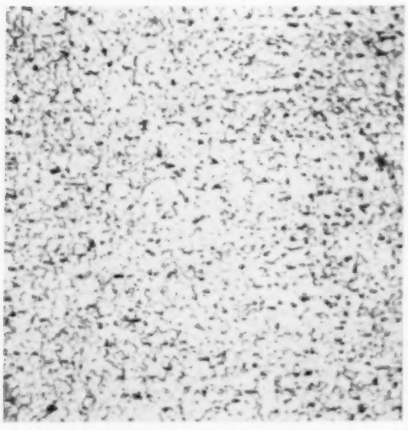


Fig. 9 — Steel As-Rolled, Finished on Cold Side, Grain Size 8 or 9, Suitable for Simple Draws

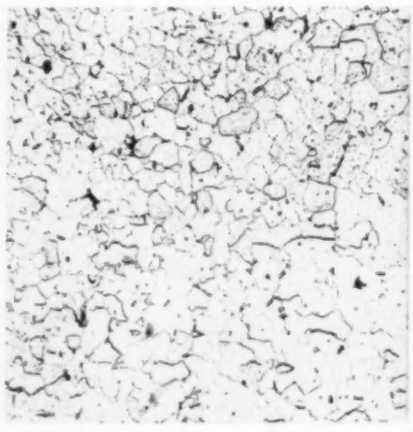


Fig. 10 — Normalized, Grain Size 6 or 7. Such stock less than 0.200 in. is suitable for extrusion

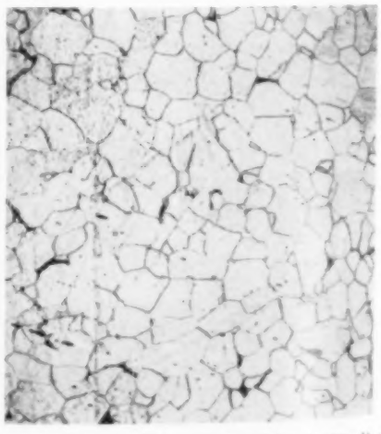


Fig. 11 — Finished on Hot Side, Normalized or Annealed; Grain Size 5; Suitable for Extrusion in Thicknesses 0.200 to 0.400 In.

CRITICAL POINTS

by the editor

WELCOMED by CHARLES LEMMON to the huge Washoe Smelter in Anaconda, Mont., where first this writer worked, a freshly graduated mining engineer — now too long ago for counting — and warmed an aging heart in the glow of good old friends. Technology was all entangled with remembrances, for the four of us, the LEMMONS and the THUMS, all started there together. CHARLEY is a perfect exemplar of an oft-repeated dictum that character and ability make more for success than formal college training. He then was field engineer on the ore road, having learned his engineering in a liberal arts college (Bucknell) and now is assistant general manager of the reduction department — a somewhat metallurgical job. ....Washoe smelter also has grown in size, although the ancient goal of one million pounds of copper a day is still par. The growth has been change and diversification. Where once were the world-renowned blast furnaces, defunct since the days of high grade ore and coarse concentrates, is now an electrolytic zinc plant. The famous big stack has been replaced with one even bigger, even stupendous, and the dust chambers supplemented by a Cottrell electrostatic precipitation plant large enough to clear all the smoke of its solid fume. (An interesting by-product is some 600 lb. daily of metallic arsenic, made by distilling the oxide with carbon, a la zinc, in cast iron retorts.) Some of the sulphur smoke is converted into sulphuric acid in a chamber plant managed by M. R. (MUCK) HOYT, another reconstructed mining engineer. Some acid goes into the electrolytic refineries for copper and zinc at Anaconda and Great Falls; the large surplus into the manufacture of triple phosphate fertilizer for mid-western sugar beet fields. The phosphate rock contains 0.16% vanadium and this also goes into solution, but can be precipitated in a phosphorus-vanadium complex by bringing the liquid to the proper pH and temperature. A simple reaction then converts the precipitate to almost c.p. V_2O_5, which is washed and finally dried in pans. Here's 400 lb. of vanadium a day as a side issue, which figures out to be somewhere in the neighborhood of 5% of the U.S. consumption.

Arsenic Metal and Vanadium Oxide—Smelter By-Products

INTERESTED in looking over the newly started department in the Anaconda smelter for the production of manganese oxide, under a three-year contract with Uncle Sam's Metals Reserve Co. The ore is a carbonate and comes from the Emma mine in Butte. During the last war some high grade ore from this mine was sent to Great Falls, Mont., where electric furnace production of ferro was getting under way at the Armistice. In the intervening years only a little has been shipped to a Butte firm for nodulizing. The most of the ore in reserve is low grade — say 25% manganese — and contaminated by lead and zinc sulphides; however the latter are easily floated off after fine crushing. A simple plan for floating the particles of manganese carbonate from the remaining valueless oxides has been worked out; the nub of the idea is to alkalinize the tailings from the lead and zinc cells with caustic. The de-watered and thickened float (manganese carbonate) is then sent to a huge gas-fired cement kiln some 270 ft. long and 15 ft. diameter. Inside the upper (cooler) end are hung hundreds of looped chains to break up and throw around the mushy feed, which as it passes along is first dried, then calcined of its CO_2, and finally nodulized into lumps, nut to

American Manganese Ore—in Quantity

fist size. The hot discharge passes, by a long pan conveyor, through a covered channel where it is partly cooled by an air draft, and then down to handling temperature in a device that works like a mechanical stoker in reverse. A continuous sample is cut from the stream as it discharges into railroad cars for immediate shipment to eastern furnaces or stock piles. The contract calls for 80,000 tons of nodules a year, to contain about 57% manganese.

Big Things in the West

WENT TO SEE Grand Coulee dam, as everyone should who gets to Washington, and was right handsomely entertained by Major S. E. HUTTON, he of the encyclopaedic knowledge of all aspects of this civil engineering, electrical engineering, and agricultural-irrigation engineering mammoth, and how it all works into the economic welfare of the Pacific Northwest. Mammoth it undoubtedly is, but there's no scale by which the eye can measure its bigness. It's in big country. To hear that the dam is three times as big as any other man-made thing does not mean much because the other man-made thing is absent; round about are just ordinary bluffs of a valley cut into a rolling plateau by the Columbia River. To know that its crest is nearly a mile long doesn't count either in country where hamlets are 30 miles apart. Each of the 150,000-horsepower turbines which will draw 140 tons of water a second through 18-ft. penstocks might look big if they weren't completely buried in the concrete. Electrical generators — 45 ft. over all in diameter, standing 22 ft. high above the floor, and turning on shafts nearly 4 ft. in diameter and 74 ft. long — merely look "to scale" in a power house of Notre Dame's dimensions. That the trestles for transporting concrete used up 25,000 tons of structural steel, half the amount in the Empire State Building, and that to cool the concrete mass took 1700 miles (yes, miles) of 1-in. steel tubing and that 1280 resistance pyrometers are buried in the structure — all this means not so much. But once within the vitals of the thing, looking down one of the brilliantly lit inspection galleries, wide as a hotel corridor, but extending on and on until it vanishes into the far perspective — *then* you know that this indeed is an amazing, a mighty work of man!.....One of those billion dollars Uncle Sam appropriates so lavishly for munitions would build four such projects, if they could be located, each irrigating a million and a quarter acres of fertile land and having 10,000,000,000 kw-hr. of surplus power every year for homes and industry.....Just below is the city of Coulee Dam, the permanent home of 3500 people, the families of operating and headquarters' employees — a delightful garden spot. No less commendable, though temporary, is the model encampment across the river for the contractors' forces. An overflow settlement upstream, above the dam, is in unlovely contrast, but its shacks are already disintegrating as the end of the job comes in sight.

Go Slow, Young Man, and See the Country

OUT IN SEATTLE, argued with ASMembers about the best way to get a true vision of this country of ours.....Everything in it is or gets so big — big cities, big trees, big corporations, deep canyons, these tremendous plains, big talk, great rivers, high mountains — that we cannot help as a people to reflect this bigness, this expansivity so irritating to our crowded foreign friends. Heirs of this immensity, we cannot understand the tragic bickerings of Europe..... They in Seattle, being "air minded", said there's nothing like an airplane for getting you up where the country unfolds below you like a map. On the contrary, say I, the high speed of flying shortens all distances; go to the other extreme and hoist yourself on a horse. Just try to belittle Colorado to a boy who ambled ten days across its southern edge from Durango to the plains! Shed a nostalgic tear for such slow meanderings and nature communings; hail to the rushing auto, the streamliner and the airliner!

PONDERING over the figures for aluminum production, zooming up like a Lockheed interceptor, and remembered seeing figures in the Office of Production Management at last year's end showing that there would be an ample supply of ingots and fabricated forms. Since then the armament program has been increased more than once, production concentrated on bombers for Britain — big ships using much metal — and six months after that comfortable estimate was made, when production is at the unprecedented rate of 600 million pounds of aluminum ingots per year, the Boy Scouts are going from house to house collecting discarded pots and pans to eke out civilian necessities. If the daily press can be credited, plans are now

Squeeze in Aluminum

being formulated in Washington for five or six new reduction plants to increase our annual production to 1400 million pounds (700,000 tons) a year, as much as the entire world made in 1940. What with the necessary power plants, the expanded ore supply, new alumina refineries, and the rolling mills and other fabricating plants to be built, it will doubtless be 1943 before all this new metal is available.

Of course, these facts point up to one thing—a great effort to make as many airplanes as soon as possible. It will be nip and tuck between fabricating facilities and raw material supplies. Under these circumstances, an outsider looking in would suggest that aircraft designers lean much more heavily on steel as an alternative material.

Now, that would be a matter for future designs rather than present ones, for the rule today is to let *nothing* interfere with production. Certainly the bombers we are now making are not the best we can make, but the inevitable new and better designs should preferably come out of the new fabricating plants, now being or yet to be tooled up.

What can these steel-using designs be?

We might have the medium sized craft with steel skeleton, similar to our present trainers, with fabric, plastic or laminated cover, well armored, and for auxiliary uses in areas where air supremacy is reasonably well maintained by fast, vicious fighters.

We might have medium or big ships with all steel wings, clad with stainless sheet, leaving the more bulky aluminum alloys for the fuselage, where the working stresses are low and the design is based on stability considerations rather than strength.

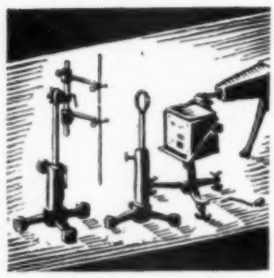
Why Not Use More Steel for Aircraft

Lastly, the big ships might have steel wing spars where stresses are high. (Mr. JACKMAN described, in his leading article in METAL PROGRESS last month, his method of strengthening these members, weighing about one seventh of the entire structure. The construction of these big wings, to carry a couple of engines each, seems so extraordinarily complicated as to suggest that the limits of aluminum sheet have about been reached. Or if heavy extrusions are being tapered for main members, it makes you weep to see 35 or 40% of the metal reduced to fine millings.) Mere substitution would not do, since steel and aluminum in composite members share the loads, and the modulus of steel is three times as high as aluminum. However, successful substitution might make ten bombers grow where nine do now.

These specific suggestions are, obviously, those of an outsider looking in. Several men in the aircraft industry have told him their objections to more steel in their structures (even though they use steel exclusively in engine mounts and landing gear). Some of these objections would not impress men more familiar with the material. Admitted, there would be a shortage in the required steel shapes, tools, welders and heat treaters, but these shortages would quite quickly vanish by the application of priorities. The *materials* now exist, which is more than can be said for aluminum and magnesium fabrications. To the objection that it is hard to heat treat steel (or any metal) without warpage, it may be said that fabricated steel aircraft beams of great variety have already been heat treated successfully in lengths up to 24 ft. Finally, why worry too much about corrodibility in a structure whose expected life is so short? Anyway, material that is admittedly durable enough for an engine mount should be suitable for a wing beam.

INTERESTED to learn that all the copper concentrates made at the huge Magna and Arthur Mills of the Utah Copper Co. are treated to recover molybdenite, and from the 80,000 tons of ore mined and crushed daily some 24 tons of MoS_2 are recovered. The ore from the mountainous mine in Bingham Canyon, in which copper is impregnated fairly uniformly, varies widely in molybdenite, the latter mineral having been deposited in a later enrichment. Even at best, the quantity is measured in a few hundredths of one per cent. That's getting needles out of haystacks for you but, as the Scotch say, "Monny a mickle makes a muckle." . . . . As is perhaps well known, the Utah Copper Co.'s mills have a relatively simple flow sheet: *(a)* Fine grind, *(b)* float. Also perhaps it would be well to explain to many ASMembers that flotation concentration defies the natural laws of the old-time gravity concentration, wherein the

heavier sulphide minerals settled in a pulsating water current, and so separated from the lighter quartz and valueless mineral which were washed away. (Panning for gold is a simple example.) In flotation a little oil is added to the finely ground ore with about four times its bulk of water. The "cell" is a simple box, at one end of which a spinning impeller whips up the mixture into a froth, and for some strange reason the sulphides are carried up in the foam and are skimmed off. . . . . Most of the molybdenum sulphide in the Utah ore floats off with the copper sulphide; the problem of separating the two economically, as solved by the technical staff, is a masterpiece of "differential flotation" — that is, making one sulphide float and the other sink. ROY HATCH, assistant general superintendent of mills, described to me the operation in much more detail than need be repeated here. Briefly: To the copper concentrates (mixed with about 80% water) a chemical is added which acts as a "depressant" to the molybdenite; as the slurry goes through a series of ordinary flotation cells the *tailings* contain the molybdenum. The latter product analyzes from 3 to 8% MoS_2; too much attention cannot be given here to molybdenum recoveries, for the mill is essentially a copper producer and nothing can be permitted to interfere seriously with this main function. Some 400 tons of these molybdenum-enriched tailings are produced daily. They are first calcined lightly in Wedge roasters. This accomplishes three things: 1. It destroys the previously used flotation and depressing reagents; 2, it drives off the frothing oil; and 3, it causes some change in the nonmetallic minerals, making them amenable to the subsequent separations. The cooled calcine is mixed with water, correctly alkalinized, and a "frother" added whereby the insoluble is floated and discarded, leaving tailings that contain principally copper, iron and molybdenum as sulphides. This material is then further conditioned with other reagents so that now only the MoS_2 will float. The final result of a rather complicated series of cleanings is a flotation concentrate that runs more than 90% MoS_2 and less than 1¼% copper. This is filtered, dried, put into bins containing a day's run, sampled and analyzed. Sometimes it is necessary to blend the product from various bins to meet specifications. . . . .One speculates on the present location of the thousands of tons of molybdenum smelted with the copper concentrate before it was separated. Did it enter the slag, did it go off with the smoke, or was any of it caught in flue chambers or Cottrell plants? No matter where this lost metal is, the Utah mills alone are now making about 9 million pounds of molybdenum (metal content) per year. The other western porphyry copper mines are also producing the mineral by analogous methods and from 11 to 12 million pounds of by-product molybdenum may be expected from these combined sources in the next 12 months.



Finding 5 Oz. Molybdenum in Each Ton of Copper Ore

SADDENED by the hint, from a friendly advertising agency, that the reading pages of METAL PROGRESS are somewhat stodgy. They try to be brief and accurate. Perhaps we'd better take a poll of reader preferences about the correct way of reporting metallurgical events. . . . .For instance, last November we said (all too briefly): "JOHN GIER of Westinghouse makes protective atmospheres low in CO_2 and H_2O by burning gas in limited air in a mass of catalyst, and tests its effect on steel by drawing it over a fine wire, heated in a test tube (see METAL PROGRESS, October 1940, p. 566)." . . . .Behold how it might have been reported: *Headline* — "Blitz Gas Polishes Aircraft Parts in Single Instant". *Catch paragraph* — "Out of the poison fumes of a furnace comes a scientific genie which in one single instant does a polishing job on America's new war planes which used to take days". *Body of story* —

To Blurb, or Not to Blurb

"Aircraft parts undergo finally a heat bath to harden them. It lasts long enough so the ordinary result is a scaly piece of metal that must be pickled and polished, taking time — that priceless commodity. The new Westinghouse discovery now eliminates a bottleneck of bolts, nuts, shafts and gears. It is a poisonous genie whose essential part is the automobile exhaust gas, carbon monoxide; without it some of the carbon in the steel vaporizes and escapes, causing scale. The poison gas presses on the steel parts and keeps the amount of carbon in the softened skin at par. A scientific Aladdin's lamp has been devised to call forth the correct genie for every type of steel. Every part then comes out brightly polished."

WHY ARE METALS SO SOFT?

By E. N. DaC. Andrade

Abstract of James Forrest Lecture on "The Mechanical Properties of Solids" before Institution of Civil Engineers, The Engineer, *June 13 and 20, 1941, pages 380 and 394*

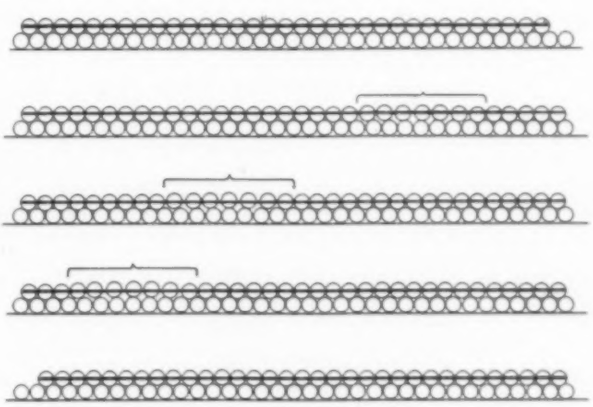
THE LECTURER started by reviewing the differences between the atomic architecture of gases, liquids and solids, and mentioned that it was very difficult to account for the mechanical behavior of solids (particularly plastic flow, ultimate strength, increase of strength by cold work, and fracture). The ultimate particles of matter are so close together in a solid that the intermolecular forces are of prime importance. Packing is almost equally close in a liquid, but the essential difference is that the liquid cannot support any internal stress permanently. Another very significant difference is that the liquid's physical properties are perfectly definite, while some of a solid's properties (density but particularly its resistance to stress) vary widely according to the past history of the specimen. Solids are therefore said to be "structure-sensitive" and this shows one thing clearly, that actual crystals cannot consist of atoms or molecules arranged in the *perfect* pattern contemplated by the mathematician — on a perfect lattice, to speak in more technical language — nor can they be in thermodynamic equilibrium.

It is possible to compute the breaking strength of a perfect crystal from our knowledge of atomic forces. The force theoretically required to separate one atomic plane from another is some 40 times the tensile strength of the strongest metal. Instead of pulling the piece apart, if we try to slide one plane of atoms over another plane, or, say, one row of atoms over another, the distance between two adjacent atoms first increases and then decreases again. It would seem logical to assume that if a stress be sufficient to cause the plane to move one half of one atomic step with reference to the neighboring plane, then it should be sufficient to cause it to execute any number of steps; a shearing stress exceeding a certain value would produce indefinite glide of one plane over the other. Calculations for the theoretical shear strength on such a supposition gives a value some 40 times that observed for steel.

On the basis that there is nothing radically wrong with these theoretical views and computations, it is necessary to harmonize them with the observed action of large single crystals under stress, and with plastic flow and strain hardening of commercial metal, which, of course, is a polycrystalline aggregate. It has been suggested that invisible surface cracks (about as deep as two wave lengths of light) may be the cause of weakness of fibers far below their theoretical strength, and many experiments have been made that support this view, among them being one that showed unmistakable signs of concentrated strains along definite crystalline directions far earlier than permanent slip occurred (in the identical directions).

"Single" crystals (rather than "perfect" crystals) have been made by metallurgists in various ways. The existence of tiny flaws *within* the crystal has been postulated to help explain the fact that shear slip in such crystals takes place on certain planes only, leaving the metal between relatively undisturbed. In general, the spacing of the slip planes becomes wider and wider as the temperature is raised. It has been suggested that the choice of the particular region where marked glide takes place may be local impurities, but experiments carried out in my laboratory with wires of exceedingly pure solid mercury (the impurity was probably about one in a hundred million) show that this cannot be so.

(Continued on page 232)



Model Illustrating Glide (Slip) as a Movement of a Few Atoms at a Time, in Effect Transferring a Discontinuity From One Place to Another

VERTICAL ILLUMINATION

for macros

By George K. Manning
Chicago Metallurgical Dept.
Republic Steel Corp.

HAVE YOU EVER used words printable only as *-? and !!,?* when looking at a carefully taken macrograph and finding that much of the detail clearly visible to the eye was not revealed on the negative? We have, frequently, and we have also found that in many cases vertical illumination is just as helpful in making a macrograph as it is in making a micrograph.

The principle used is identical with the principle used on all metallographic microscopes. Figure 1 indicates the arrangement. A No. 1 photoflood bulb in a common photographic reflector, placed 2 or 3 ft. from a plate of diffusion glass, will provide sufficient light to properly expose a negative with a Weston rating of 8 in 3 sec., when the camera lens is stopped to f8. The ground glass used in Republic Steel Corp. laboratory is 8×7 in. and the plate glass which acts as a reflector is 8×10 in. The two may be conveniently held in place by two boards each containing a vertical and a 45° slot.

It is usually desirable to place the plate glass reflector as close to the camera lens as possible and thus keep the distance the light travels from the ground glass to the object a maximum. This scheme reduces the amount of oblique light that finally reaches the camera lens. Still greater contrast may be obtained in the object being photographed by moving the ground glass further from the plate glass reflector toward the light source. The object being photographed should be placed in the bottom of a box which has been lined with black photographer's paper to eliminate any glare from direct light striking its corners. Once the necessary materials are obtained the equipment may be set up and adjusted quite quickly.

In order to judge of the possibilities a few comparative views will be shown of the same objects, photographed under oblique illumination and under vertical illumination as described above.

Figure 2 shows the hardening pattern of two smooth cross-sections with oblique and vertical illumination. It will be noted immediately that the hardened rim photographs dark when obliquely lighted, and white when vertically lighted, and that

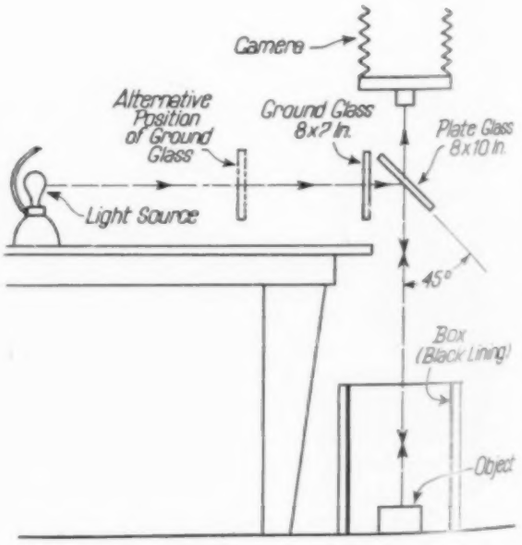


Fig. 1 — General Arrangement of Improved Lighting for Macrography

these conditions are reversed for the unhardened core. This reverse effect is likely unless the piece is over-etched to the extent that the outer martensitic area is roughened and is no longer a mirror surface. Tedious and time-consuming etching processes are usually necessary to roughen the martensitic area without staining so it will photograph white under oblique illumination. As the carbon content of the sample is lowered it becomes increasingly difficult to produce sufficient contrast between the hardened and unhardened zones. However, if vertical illumination is used a simple 2% nital etch does very well. An etch which will clearly reveal the structure at 50 or 100 magnifications under the microscope will generally produce the desired results in a macrograph taken with vertical illumination. Hardening patterns in 0.25% carbon steels may also be made to appear. Any pattern visible to the naked eye will be evident on the negative.

Figure 4 is of two fractures taken with vertical and oblique illumination. The samples appear somewhat more natural under vertical illumination and the dense shadows on the sample photographed with oblique illumination are eliminated.

Likewise, oblique illumination gives no hint of the extremely coarse grain size of the sample shown in Fig. 3, whereas vertical illumination brings out the ferrite pattern that was visible to the eye.

Each kind of illumination has its proper application. Vertical illumination will be found to be very satisfactory when photographing flat or nearly flat surfaces. When it is necessary to indicate contour and depth in the photograph, oblique illumination serves the purpose far better.

Oblique Vertical

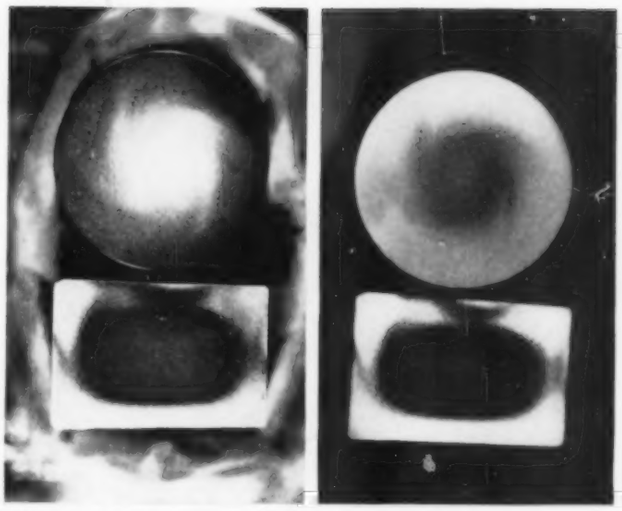
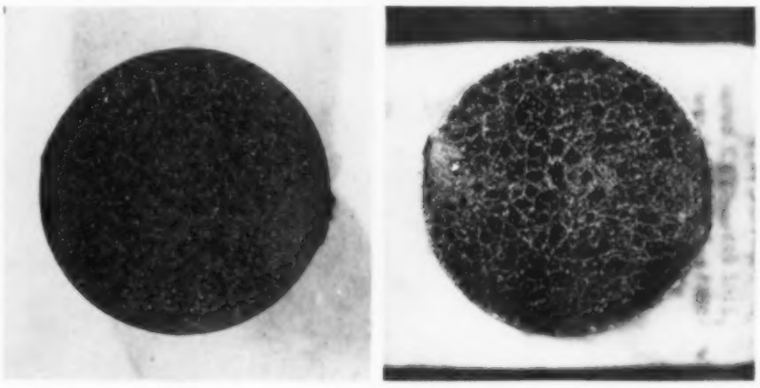


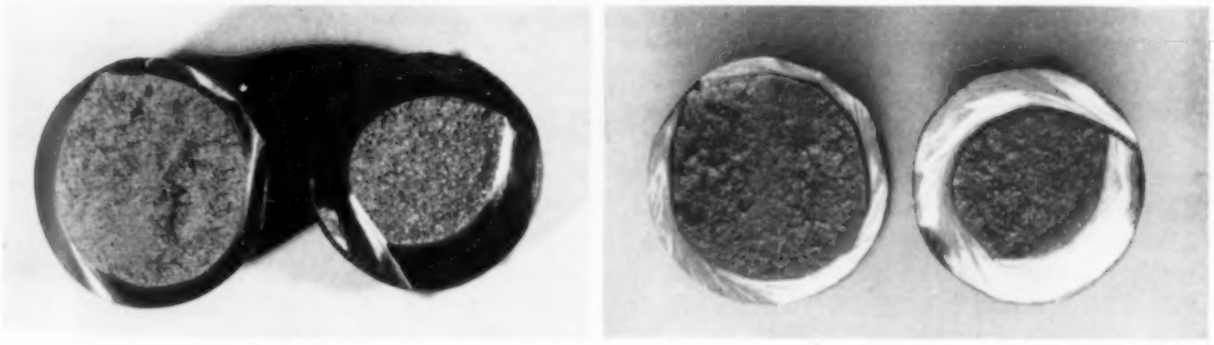
Fig. 2 (above) — Depth of Hardening Observed in S.A.E. 1040 Round and 1065 Rectangular Bar. Smoothed, etched with 2% nital and magnified 1½ diameters

Fig. 3 (below) — Coarse Grain (Ferrite Network) in Forged S.A.E. 1045 Clearly Photographs Under Vertical Illumination. Surface is too smooth to reveal fine contrasts under oblique light. Nital etch; actual size

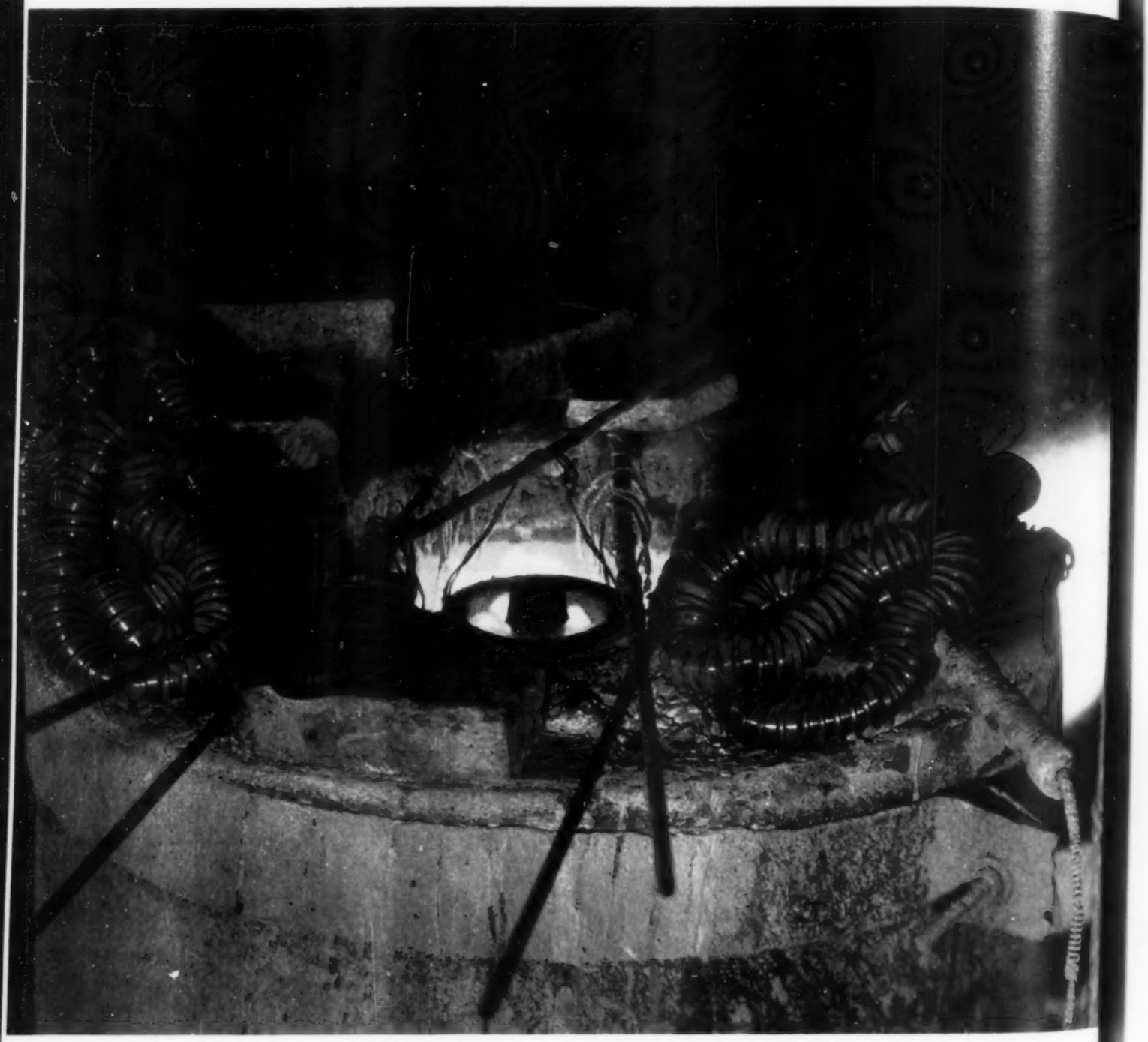


Oblique Vertical

Fig. 4 — Fracture of Two Bars, Photographed Natural Size Under Two Methods of Illumination



Oblique Vertical



Activated Salt Bath for Surface Hardening by the Chapmanizing Process. Strings of small parts are mildly preheated while resting on the furnace casing. Photographed at Lakeside Steel Improvement Co., Cleveland

SELECTION OF STEEL

as influenced by the equipment in the heat treat

By Gordon T. Williams
Metallurgist, Deere & Co.
Moline, Ill.

A PRIME CONSIDERATION in the selection of steel to be used for a given part lies in the heat treating procedure which can or must be used. This importance is not too apparent at first glance, but a moment's consideration will give it proper significance. For example, a first question one might ask is, "*Can* we perform the treatment required on this part if we use such-and-such a steel?" The metallurgist or foreman may be called in and asked; he might reply, for instance, "We'd have to oil quench the stuff; the only oil tank we have is alongside the small furnace, which wouldn't take this piece; all we have near the big furnace is water. Besides, you remember we took out that oil tank six months ago."

The problem of available equipment as it affects the selection of steel is not limited to small plants. Think of a large plant where a production line of furnaces has been assembled over the years to handle certain heat treatments; a change in procedure may necessitate extensive and expensive changes. Of course, if the company is big and rich enough, that is another thing. I once was told by a heat treat manager that a certain large continuous special furnace was to be torn down because it wasn't needed for the "new model"; besides, it only cost $35,000 two years ago and it had already paid for itself, and they didn't have space or desire to store it against possible future need. Few of us are in that position!

The part played by the existing heat treat in steel selection may be suggested in the following paragraphs:

Annealing (implying cooling in the furnace or other retarded cooling): Is there furnace capacity enough to permit the necessary cycle to be followed? Some steels demand long, slow cooling periods, and may tie up a furnace completely for many hours. Also, bear in mind that reduction in warpage of carburized and hardened parts is favored by annealing (or normalizing) at a temperature higher than that used for carburizing, say 1750°, and that many furnaces won't reach this temperature, or stand up very long under such conditions.

Carburizing: The adoption of a carburizing steel, if required, may necessitate provision for an operation not previously performed. If the size of the job warrants purchase of equipment, well and good; too often this is not the case. Occasional pieces can be packed in home-made boxes, pieces of pipe or the like, if proper containers are not on hand. Direct quenching (the No. 1 favorite on today's heat treat parade) is often not easy to carry out without special provision; usually continuous gas carburizers are installed where it is desired to quench direct. Unfortunately, many plants cannot afford these

big units. An oil tank must be provided close to the furnace discharge point and, if work is pack-carburized, a dumping screen is desirable. Slow cooling from carburizing simply demands space where the work can be cooled, protected from contact with air, apart from the furnace so that the latter is not tied up unduly. Temperature uniformity must be good within the furnace if case depth uniformity and minimum warpage are to result.

Heating for Hardening: Obviously, a furnace big enough to hold the work is needed, but temperature uniformity must be adequate; for this reason, likewise, a large furnace is not usually desirable for very small pieces. (The proverbial needle-in-the-haystack has nothing on the difficulty of finding a small red-hot piece on the hearth of a large red-hot furnace.) The furnace used must have a suitable heating rate so that an excessive heating time, with accompanying heavy scaling, is avoided. And, speaking of scale, the expectation in this respect must be borne in mind, namely, potential hardenability depends on the quality of the quench, and an excessively scaled piece may fail to respond to a quench which would harden a clean or lightly scaled piece. Use of atmosphere-controlled furnaces for the hardening heat may make the quench effective enough so that a lower priced steel of lower hardenability may be adopted. The lower the hardenability of the steel, the greater will be the handicap imposed by scale. And, of course, the detrimental effect of scale is far more evident in oil quenching than in water quenching, since the violence of the latter usually blasts off ordinary scale.

Quenching: Fundamental indeed is the influence of the quenching medium as a factor in steel selection. Water quenching is obviously the first choice, because of the ease of circulating it and controlling its temperature, as well as for its scale-removing property. But water often gives irregular hardening due to incomplete scale removal and to formation of steam pockets; a 9% brine or 3% caustic soda solution will normally give better uniformity of hardening than water, with less warpage or tendency to crack. These solutions, like oil, demand the use of circulating pumps or agitators, and adequate provision for cooling, usually by pipe "radiators". Oil will often be required as a quench medium if warpage is to be minimized; a tank large enough in size to handle the work, and of capacity to avoid overheating the liquid, must be provided. (Useful rule-of-thumb: A gallon of oil or water solution capacity per pound of work quenched per hour will give good results without excessive cooling equipment.)

Consequently, a good starting point in steel selection is "How will we quench it — water or oil?" Plan to use water or a water solution unless considerations of warpage or cracking enter the picture; if an alloy steel with good hardenability is to be used, oil quenching will usually be necessary.

Tempering: Availability of temperature uniformity in the necessary tempering operation must be assured. Many small plants have no adequate furnace for obtaining temperatures below 900° F. or so (above that, fair results *may* be obtained in box furnaces).

Conclusion

The above considerations are probably obvious, but serve to show that the available equipment for heat treatment will have some influence on the selection of steel for a given part. Sometimes the experience of the heat treater with various steels is also a factor. In any event, the heat treater may be able to offer some worth-while suggestions to the man who is selecting the steel.

Of course, now and then a new job comes along that is important enough, or the economics of which are such that the steel selected will require or permit purchase of equipment. Then the path is more clear, but the new equipment should be selected with a view to its use for other parts as well, hoping thus to improve the overall operation of the department.

ABRASIVES

in the role of

super-refractories

By Henry C. Fisher
Research Laboratories
Norton Co., Worcester, Mass

ALL ABRASIVE MATERIALS are refractory to some degree; that is, they have either a moderate to high fusion point or decompose only at a high temperature. However, not all abrasive materials are suitable for refractory purposes, although they may be highly refractory. Conversely, not all materials possessing the property of refractoriness are suitable for abrasives.

An abrasive may be broadly described as any material which will, because of difference in hardness, scratch a material softer than itself.

The definition of an abrasive as generally understood by the trade is quite involved. My associate L. H. MILLIGAN prefers to characterize an abrasive in terms of hardness, brittleness, ductility, plasticity, and modulus of elasticity in the following way (February 1941 *Bulletin* of the American Ceramic Society):

"The first requirement of a good abrasive may be expressed by saying that it must have a hardness similar to or preferably greater than the material being abraded. The usual abrasives are brittle materials, in that they are non-ductile and non-plastic. Curves plotted to show their stress-strain characteristics are straight lines right up to the point of failure. They are characterized by high modulus of elasticity, and the harder they are, the higher is their modulus of elasticity likely to be. Abrasive materials are also characterized by high mechanical strength."

A good abrasive must also possess a reasonably high degree of refractoriness. In many grinding operations considerable heat is generated and, unless the abrasive is relatively unaffected by the heat thus generated, its abrasive characteristics will probably be impaired.

In defining "refractoriness" A. B. SEARLE uses the following in his book "Refractory Materials; Their Manufacture and Uses":

"*(a)* To indicate the resistance of a material to the action of heat, quite apart from any accompanying conditions, such as the effect of atmosphere in which the material is heated.

"*(b)* To indicate the resistance of a material or article to heat under conditions of use, including the effect of hot gases, abrasion or corrosion by the contents of the furnaces, etc., which are seldom defined in detail."

The term "super-refractory", used in the title of this paper, signifies a superior refractory. However, it should not be assumed that super-refractories are capable of meeting all conditions. Actually, no *perfect* refractory exists.

There are certain advantages in using the term "special refractory", as employed by H. E. WHITE in an article in *Industrial Heating* for October 1938, for classifying highly refractory, crystalline materials. A special refractory thus indicates a crystalline material possessing a high degree of refractoriness, above that of ordinary

materials, and one whose physical properties permit its use to advantage under special furnace conditions; it need not meet all furnace conditions. The ones designated by him are fused alumina, mullite, and silicon carbide. Electrically fused magnesia or periclase should also be included. Other materials such as thorium oxide and beryllium oxide, because of their high degree of refractoriness, might also be included, but since their present uses are limited, no further consideration will be given to them in this paper.

as 1800° F. (1000° C.); however, only a small amount of glass phase is formed by melted impurities at temperatures below 3200° F. (1700 to 1800° C.), and the actual temperature at which the whole mass becomes liquid is in excess of 3450° F. (1900° C.). It must be borne in mind that the softening range may not be the determining factor so far as the effectiveness of the refractory is concerned.

A highly refractory bond is mixed with the abrasive grain and a mixture is obtained that is itself useful as a refractory cement. It may

Table I — Characteristics of Bonded Refractory Electric Furnace Products *(a)*

Material	Purity of Grain	Fusion Point of Pure Material	Bonding Material	P.C.E. *(b)*	Standard Brick		Deformation at 1500° C. *(c)*	Resistance to Thermal Shock	Electrical Resistance	Thermal Conductivity
					Porosity	Weight				
Fused alumina (Al_2O_3)	94+% Al_2O_3	2050° C. (3725° F.)	Clays	37+	19 to 21%	11.5 lb.	2.0%	Low	Medium high	High
Fused alumina (Al_2O_3)	99.5+% Al_2O_3	2050° C. (3725° F.)	Clays or chemicals	39+	20 to 23%	11.5 lb.	1.0%	Low	High	High
Silicon carbide (SiC)	98% SiC	Decomposes at 2300° C. (4175° F.)	Clays or none *(d)*	Variable	17 to 20%	9.25 lb.	None	Very high	Generally low	Very high
Electrically sintered magnesia	95+% MgO	2800° C. (5075° F.)	Clays or chemicals	39+	20 to 23%	10.5 lb.	*(e)*	Very low	Very high	High

(a) In every case the characteristics will vary with variations in bonding material, density of product, heat treatment and other manufacturing variables.

(b) Approximate pyrometric cone equivalent of material mixed with necessary bond.

(c) Standard load test, 50 psi.

(d) Recrystallized silicon carbide is made without bonding material.

(e) Fails by shearing between 1450 and 1500° C. (2650 and 2750° F.) depending on mixture.

Abrasives Available for Refractories

Table I summarizes typical characteristics of bonded refractory electric furnace products.

When considering refractories, we should not limit ourselves to abrasive materials, for many abrasives are not suitable for refractory purposes; furthermore, our hardest abrasives, diamond and boron carbide, are not suitable for refractories. However the synthetic abrasives, fused alumina (Al_2O_3) and silicon carbide (SiC), *are* suitable for refractories, and they will be considered first.

Fused Alumina. The fusion point will vary with its degree of purity.

Fused alumina is usually produced in two grades. One grade contains between 94 and 95% Al_2O_3, the remainder being TiO_2, SiO_2, Fe_2O_3, and other oxides. In the fine grit sizes, sintering will commence at a temperature as low

be molded into various shapes which, after firing, are serviceable at temperatures above 3000° F. (1700° C.). Such mixtures may be used as ramming mixtures for lining furnaces used for melting various metals; as burner tunnels for gas-fired and oil-fired furnaces; as plates for the construction of tunnel kiln muffles or enameling muffles (Fig. 1); as tile or standard brick for pier brick and for furnace bottoms; as porous mediums; and as cements for embedding electrical resistance elements.

Listed in the second line of Table I are data about a higher grade of fused alumina containing more than 99% of Al_2O_3, the remainder being largely Na_2O. This material will have a fusion point close to 3700° F. (2050° C.), the fusion point of chemically pure Al_2O_3. Part of the Na_2O present will be volatilized at temperatures above 2200° F., and there can be but little fluid phase below 3600° F.

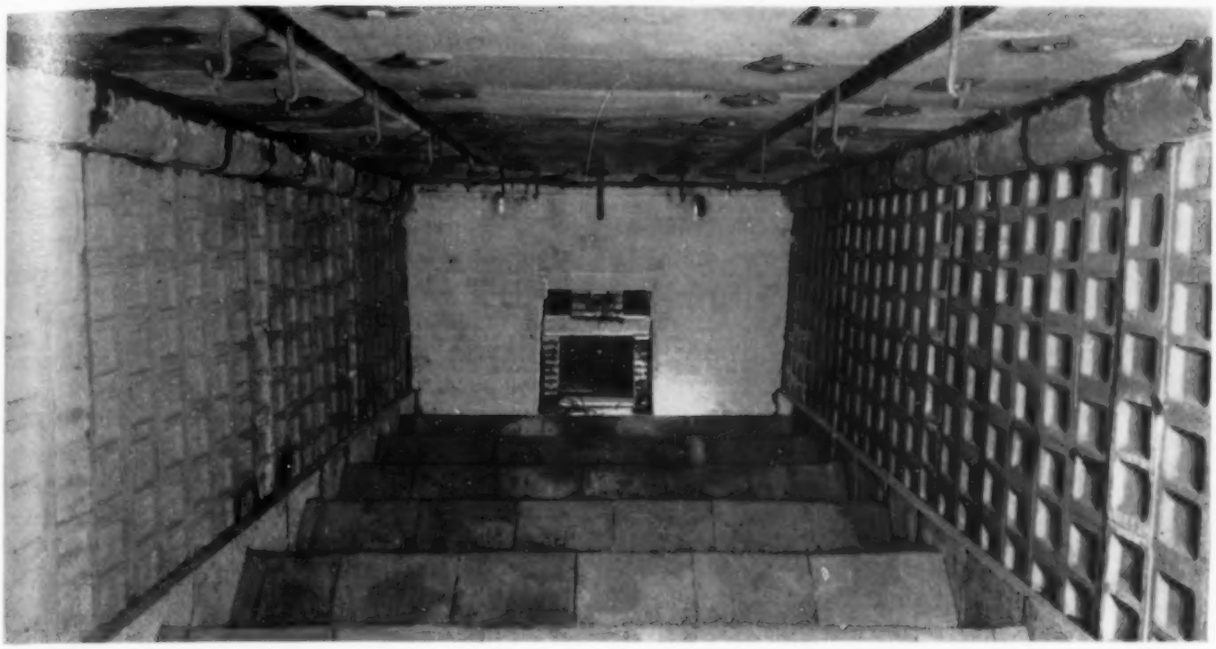


Fig. 1 — Construction View of Interior of Continuous Enameling Furnace With Bottom Tile and Lower Side Walls of Fused Alumina. Work is carried on travelling hangers which loop at far end and return

In general, the uses of this higher grade of fused alumina are similar to those for the less pure material. It has a higher degree of refractoriness and is an excellent material from which to make laboratory ware, pyrometer tubes, cores, tubes, and muffles for electrical resistance furnaces wound with nichrome, molybdenum, tungsten, or platinum wire. Relatively large quantities are used in fine grain sizes in the radio industry for tube insulation. Other uses include electrolytic diaphragms, tower packings and carriers for catalyzers.

Silicon Carbide. Since most refractory materials are oxides, silicates, or mixtures of oxides and silicates, silicon carbide is unique. In many respects it reacts to furnace conditions in a decidedly different manner. Its ability to transfer heat is on an entirely different scale than the other special refractory materials, as shown in Fig. 2.

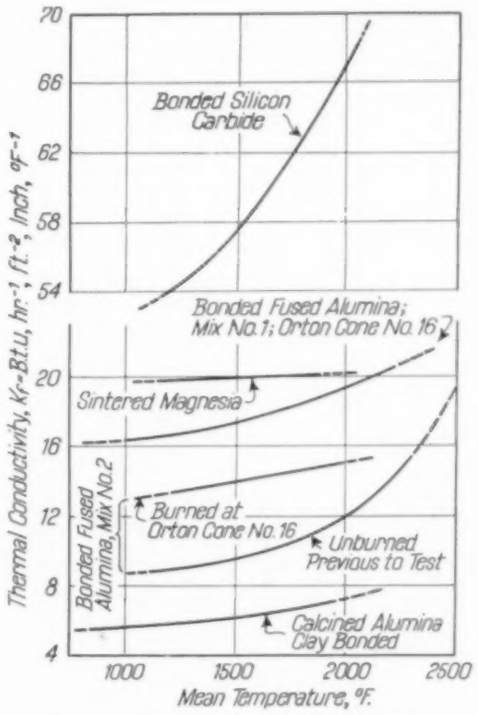


Fig. 2 — Heat Transfer of Special Refractory Materials as Determined at Various Elevated Temperatures by Prof. Gordon B. Wilkes of Massachusetts Institute of Technology

Silicon carbide does not "melt" at atmospheric pressures, but decomposes at temperatures in the neighborhood of 4200° F. (2300° C.). Its resistance to deformation under load is good; also, it is relatively insensitive to temperature change. Its principal uses are for lining the clinker zone in stoker-fired boiler furnace walls because the clinker does not adhere to it; for hearth plates for underfired heat treating furnaces because of its strength, resistance to spalling, and heat transfer properties; for recuperator tubes. Under certain conditions, it is used for the construction of muffles in enameling furnaces. It also finds a use in muffles for small resistance-wound electric furnaces, for small gas-fired furnaces, and for zinc distillation retorts. Its excellent load-carrying characteristics and spall resistance make it an

ideal material for tunnel kiln car tops, supports, plates, rings and saggers, and kiln furniture generally.

The tendency for silicon carbide to oxidize at temperatures between 1500 and 2200° F. (800 and 1200° C.) impairs its suitability for specific uses. Also, bonded silicon carbide refractories are not generally used at temperatures much in excess of 2900° F. (1600° C.).

Non-Abrasives

Other synthetic refractory materials not classified as abrasives may be listed as follows:

1. Electrically fused magnesia (MgO)
2. Mullite ($3Al_2O_3 \cdot 2SiO_2$)
3. Spinels ($MgO \cdot Al_2O_3$) or ($FeO \cdot Cr_2O_3$) or ($MgO \cdot Cr_2O_3$)
4. Forsterite ($2MgO \cdot SiO_2$)

Electrically Fused Magnesia. Some experimenters quoted in "Handbook of Chemistry and Physics" have given the fusion point of pure MgO as 5075° F. (2800° C.). The fusion point of the electrically fused MgO will probably be somewhat below this, because of slight impurities. Sufficient quantities to fill commercial requirements are not obtainable in the pure form; this is ordinarily unnecessary. Usually small amounts of clay or iron oxide are used as bonding ingredients; occasionally magnesium chloride. Electrically fused magnesia is used generally as a ramming mix wherever a basic lining is required to resist a highly corrosive slag. The material has a relatively high heat transfer value, but is mechanically weak at high temperatures and is decidedly sensitive to thermal shock.

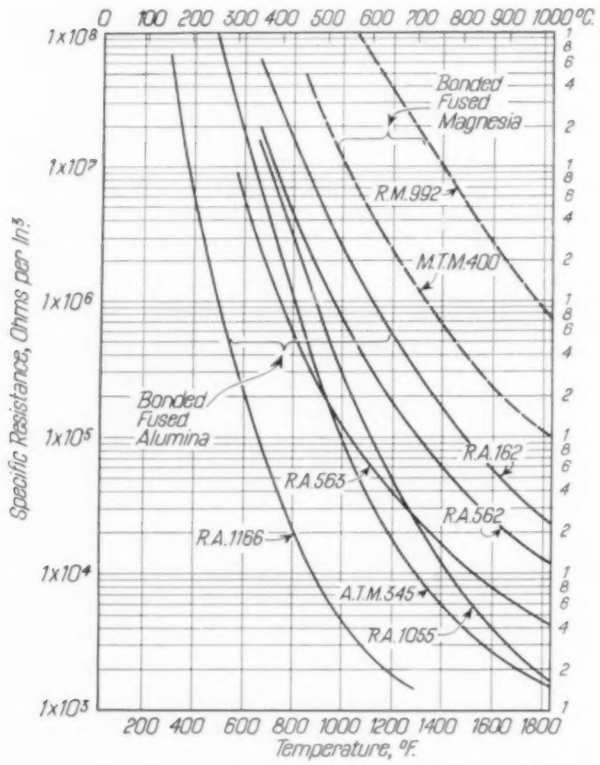


Fig. 3 — Electrical Resistance at Elevated Temperatures of Various Mixes of Magnesia (Bonded and Fused) and of Alumina

Large quantities of selected magnesia are fused and treated for use as electrical insulation. It has a high electrical resistance at high temperatures, making it eminently suitable for insulators either in powder form or in cement mixtures. Figure 3 gives the specific resistance at temperatures up to 1800° F. (1000° C.) of various refractory cements made with fused magnesia and fused alumina.

There are a number of mullite refractory products that are made by molding in the usual manner with added bond and then firing. However mullite is also formed into blocks by casting from the liquid phase, the molten material being merely poured into appropriate forms and allowed to solidify.

Such cast refractories constitute an interesting product and have particular merit where an impervious lining is desirable in furnaces operated continuously for long periods of time without shutdown. The prime use is for lining glass tank melting furnaces.

There is not much that can be said with respect to spinels and forsterite at the present time, but several recent patents have covered their manufacture. Their properties may make them useful in steel melting furnaces under certain conditions. Forsterite, the magnesium orthosilicate, has been discussed in a recent paper by Gilbert E. Seil and staff in the *Journal* of the American Ceramic Society for January 1941.

Natural Refractory Minerals

This discussion would be very incomplete if we omitted mention of some refractory minerals occurring naturally. They fill the gap in refractoriness between that of the fireclays and "special refractories". These are:

1. Corundum (Al_2O_3)
2. Bauxite (colloidal $Al_2O_3 \cdot 3H_2O$)
3. Diaspore ($Al_2O_3 \cdot H_2O$)
4. Sillimanite ($Al_2O_3 \cdot SiO_2$)
5. Andalusite ($Al_2O_3 \cdot SiO_2$)

7. Kyanite ($Al_2O_3 \cdot SiO_2$)
8. Kaolin ($Al_2O_3 \cdot 2SiO_2 \cdot 2H_2O$)
9. Zirconium oxide and silicate—(ZrO) and ($ZrO \cdot SiO_2$)
10. Chromite ($FeO \cdot Cr_2O_3$)
11. Silica (SiO_2)

Selection of a Refractory

The selection of a refractory to meet a given set of conditions usually is no simple problem, governed as it is by a set of conflicting factors, some beyond the user's control. There is no perfect refractory; consequently, we must balance the desirable properties of the available materials against their undesirable properties, and select one which will most nearly fulfill the needs, bearing in mind that it may be necessary to sacrifice length of life or some other property.

Table II estimates the relative factors for determining the usefulness of commercially available products, and is presented as a basis for making an initial approach by the user to the selection of a refractory for a new purpose or to avoid existing difficulties with another material. This classification is only approximate. It makes no attempt to a clean-cut distinction between the various types and uses. There are many large overlaps in properties and in suitability. Commercial materials vary widely in degree of purity and the manufactured products vary in structure.

The table further emphasizes the fact that there is no perfect refractory and that in the selection of a refractory it is necessary to make a series of compromises. The evaluations: 1, for very high; 2, high; 3, medium; 4, low; and 5, very low, only show the general relationship. For example, under the heading of "Refractoriness", fireclay is listed as 3 (medium). This is not correct in the strict sense, because there are

Table II — Relative Factors *(a)* for Determining the Usefulness of Commercial Refractory Products

Commercially Available Product	Refractoriness	Load Bearing at High Temperatures	Spalling Resistance	Heat Transfer Characteristics	Resistance to Oxidation	Resistance to Reducing Atmospheres	Acid Slag Resistance	Basic Slag Resistance	Resistance to Slag Adherence	Resistance to Slag Penetration	Electrical Resistance at High Temperatures	Weight of Refractory Article	Resistance to Mechanical Abrasion
Silicon carbide	2	1	1	1	3 *(b)*	1	1	3	1	1	5	2	1
Aluminous materials:													
Fused alumina	2	2	4	2	1	1	1	2	4	4	2	2	1
Corundum	2	3	3	3	1	1	1	2	4	3	3	2	2
Bauxite	3	3	3	3	1	1	1	2	4	3	3	3	3
Diaspore	3	3	3	3	1	1	1	2	4	3	3	3	3
Magnesium compounds:													
Sintered magnesia	1	4	5	2	1	1	5	1	4	3	1	2	3
Calcined magnesia	1	4	5	3	1	1	5	1	4	3	2	2	3
Sintered MgO with fused alumina	2	4	3	3	1	1	3	2	4	3	2	2	3
Magnesia spinels	2	4	3	3	1	1	3	2	4	3	2	2	3
Forsterite	2	2	3	4	1	1	3	3	4	3	2	2	3
Aluminum silicates:													
Mullite (fused and cast)	2	1	4	3	1	1	1	3	4	1	2	2	1
Sillimanite	2	2	2	3	1	1	1	3	4	2	2	3	2
Andalusite	2	2	2	3	1	1	1	3	4	2	2	3	2
Kyanite	2	2	2	3	1	1	1	3	4	2	2	3	2
Kaolins	2	2	2	3	1	1	1	3	4	2	2	3	2
Fireclay	3	4	2	4	1	1	1	3	4	2	3	3	3
Chromites	2	4	5	3	1	4	1	1	4	2	3	1	2
Silica	2	1	5	4	1	1	1	5	4	2	2	3	3
Graphite	1	1	1	1	5	1	1	1	1	1	5	4	5
Zirconium oxide	1	2	1	4	1	3	2	4	4	3	2	1	3
Zirconium silicate	1	2	1	4	1	3	2	4	4	3	2	1	3

(a) Relative classification:
1. Very high
2. High
3. Medium
4. Low
5. Very low

(b) This figure 3 applies to a temperature range of 800 to 1200° C. (1475 to 2200° F.); at other temperatures a No. 2 classification applies.

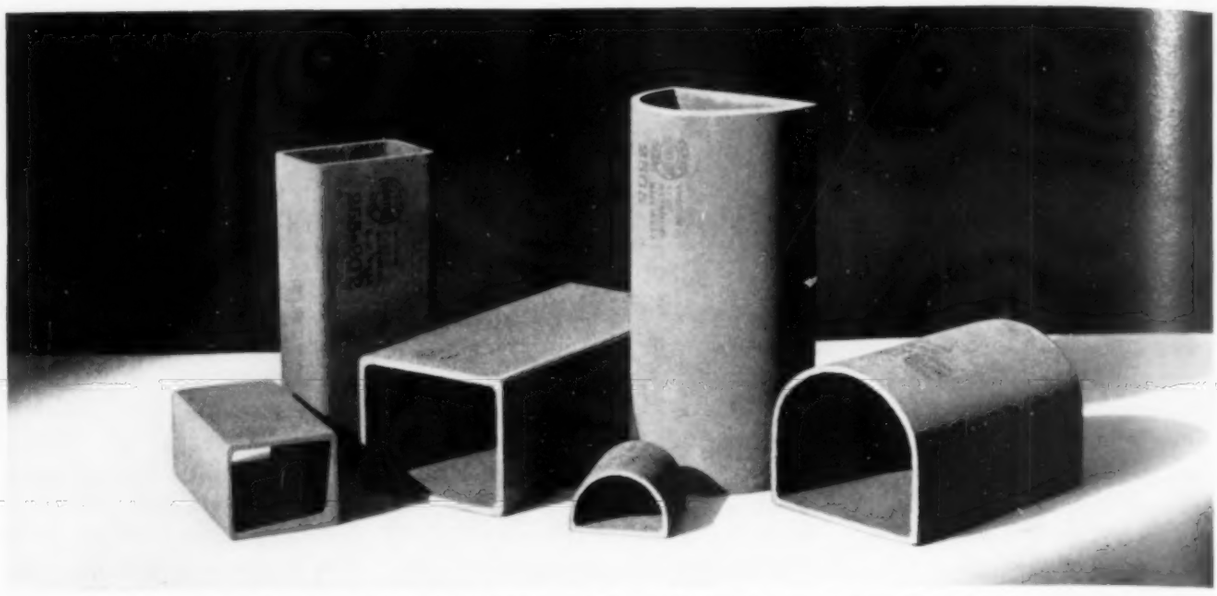


Fig. 4 — Bonded Silicon Carbide Is Molded and Burned Into Various Tubes, Tile, Brick, and Muffles

certain excellent fireclay refractories, as well as some poor ones. Many fireclays will approach the andalusite group in heat resistance.

Much information on these various products and their uses has been published, but many times the prospective user has neither the time to devote to a search of the literature nor the facilities for looking up data which will assist him in making an initial approach to the solution of his particular problem. This chart, it is hoped, will give a general idea of the type of refractory best suited for his particular need. If detailed information is desired, it can best be obtained from the producers.

The conditions which will determine the kind of refractory for a specific use may be listed as follows:

1. Kind of slag present, if any.
2. Operating temperature of furnace.
3. Furnace operation, either continuous or intermittent.
4. Furnace atmosphere, oxidizing or reducing.
5. Heating medium employed.
6. Heat transfer properties desired.
7. Kind and condition of material being charged for treatment.
8. Rate of production.
9. Electrical characteristics of refractory at furnace temperature—of great importance where electric heating is employed.

Much might be written about each of these suggested subjects, but space is not available. We can only remark on some of the most salient features.

The conditions which may make the use of special refractories desirable are as follows:

1. Operating temperatures are especially high.
2. Especially high heat transfer properties are desired.
3. Mechanical abrasion is severe.
4. Chemical erosion is severe.
5. Slag must not adhere.
6. Contamination of melt must be avoided.

In general, the special refractories described above at some length are available in at least four forms: Standard 9-in. series of bricks; special shapes, such as tubes, plates or blocks; ramming mixtures; and trowelling mixtures.

Installation is a subject that is often given too little thought. It sometimes appears to the firebrick manufacturer that the user thinks all that is necessary on his part is to order the refractory, lay it up in almost any manner, and thereafter give it little attention or none at all. Then he expects satisfactory service! Any refractory material may readily be ruined if improperly installed, or if used in a careless manner.

Bricks, blocks, plates, and special shapes are usually made to be set up according to blueprint instructions. The products have been fabricated and burned in the best possible manner by the manufacturer, and suggestions are usually given in regard to the type of mortar to be used with them.

The success of rammed linings depends largely on the installation methods. Two specific examples will be given in a later article.

CORRESPONDENCE

and letters from abroad

Centrifugal Casting with axis vertical

PENISTONE NEAR SHEFFIELD, ENGLAND

To the Readers of METAL PROGRESS:

FOREIGN CORRESPONDENCE seems to have withered down to almost nothing, and for that there are understandable reasons. However, METAL PROGRESS comes through to us with unfailing regularity, and is read with as much interest as ever — in fact, latterly more so, since American journals are beginning to be occupied with other than technical problems which engaged our own attention some two years ago. Many of these we have solved; others have become so much a part of our daily routine that it takes us back quite a good way to hear them discussed elsewhere.

At any rate, this note may revive what must be a difficult feature for THE EDITOR to print, these days, albeit a very useful department in the magazine. I would like to comment on the article "Centrifugal Casting with Axis Vertical" by NATHAN JANCO in the April issue. It is interesting and informative, and in many ways sums up the present state of the art accurately. On the other hand, the vertical axis centrifugal casting machine has not been neglected quite so much as he would have us believe. I should have thought also that the field for the horizontal axis machine was greater than for the vertical axis machine, particularly having regard to the economic possibilities.

Despite this and apart from the splendid work of your Ford Motor Co. on vertical axis machines, such casting machines have been used in England for fairly large scale production for nearly 20 years. My own rather lengthy article in METAL PROGRESS for June 1933 gave particulars of castings made on this type of machine for bronze gear blanks up to 5 ft. in diameter and one ton in weight. Since that time considerable strides have been made in this country on vertical axis machines with practically all metals and alloys, although I agree with Mr. JANCO that the field of application is yet by no means fully covered.

I would quarrel with his nomenclature where he describes the method in which a central core is used as "semi-centrifugal" casting. Such a description of this method would lead people to suppose that such were not truly centrifugally cast, which would be quite erroneous. The main object of centrifugal casting, as Mr. JANCO remarks in other words, is to use centrifugal force to "feed" the casting instead of the more normal method of large heads and force of gravity. For this reason, in my opinion, any casting which is spun and uses centrifugal force to produce greater soundness is truly a centrifugal casting. "By their fruits ye shall know them." Presence or absence of cores is immaterial, for cores are often used for castings which could be cast without them (for such reasons as securing absolute concentricity of bores with outside diameters) and there is no difference between the metallurgical results obtained.

FRANCIS W. ROWE
Chief Metallurgist
David Brown & Sons, Ltd.

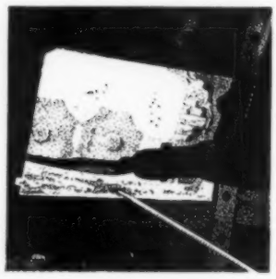
Dopes to Prevent Decarb

DUNDAS, ONTARIO

To the Readers of METAL PROGRESS:

THE EDITOR, in CRITICAL POINTS in the June issue asks whether anyone has tried the effect of copper, sprayed on with a metalizing gun.

While we have not used this for the prevention of decarburization, or soft skin after hardening, we have sprayed copper on S.A.E. 4615 parts and carburized them in the pack. We found that such a coating was only 80% effective. The reason is evidently that the coating is slightly porous and hard to apply evenly when parts have sharp corners and recesses.



In the case of "Moly" high speed steel hardened from 2200° F., copper, melting at 1981° F., would conceivably "wet out" and protect the tools from decarburization, but the tools would have to be ground all over afterwards to get rid of the copper, and that would be no fun!

L. F. TRAIN
Metallurgist
Pratt and Whitney of Canada

Stabilization of Dimensions
after preliminary creep

UGINE, SAVOIE, FRANCE

To the Readers of METAL PROGRESS:

In a letter in the March 1938 issue of METAL PROGRESS I commented on an empirical formula of the type

$$y = y_o + at^m + bt^n$$

developed by J. DE LACOMBE, engineer for the Ugine Steelworks, and intended to represent elongation-time curves obtained in creep tests. In this formula y is the recorded elongation, t the time, y_o, a, b, m, n are coefficients among which m is less than 1 (usually in the neighborhood of 0.3 to 0.5) and n is more than 1 (usually between 1.8 and 2.2).

From the numerous precise verifications which have recently been made, but without attributing to this formula any essential significance or character, the following conclusions can be reached:

First as to the significance of the early part of the creep test. In many cases one can justify its use only for distinguishing successive stages in a curve. The two exponential terms of the formula are nil only at zero time; consequently there is no apparent difference in this respect between the beginning of the curve (not only the first few hours but even the first minutes) and its ultimate development. Increasing the time of the test increases the precision of the determinations but brings out no new characteristic in the equation which was not contained in it, in principle, from the beginning.

The experimental curves so far examined show no indication that it is impossible to predict the entire curve from the initial portion. Thus it cannot justifiably be said that the first 25 hr. of test are without significance, nor that it is necessary to wait 25 hr. before establishing the correct conditions in a test piece.

2. A formula of three terms is found to be applicable to creep curves of all steels we have examined, and consequently steels cannot be classified from the *form* of the curves, but only from the values of the coefficients.

3. Representation of these curves by a parabolic form without an asymptote is incompatible with the conception of a limiting load at which elongation tends to be arrested even as time goes on.

This formula introduces the constant y_o corresponding to the beginning of an "instantaneous elongation". This instantaneous elongation can in fact be directly observed and recorded provided appropriate experimental precautions are taken, although these are sometimes rather difficult.

Using the same precautions in the observations, when the load is released after viscous elongation an instantaneous shortening is determined experimentally, which is a function of the amount the load is released and independent of the viscous elongation previously sustained. If the test piece is then again loaded, an instantaneous elongation is observed equal to the preceding shortening. In general it may be said that for a certain load the instantaneous elongation observed at the beginning of the test is greater than the subsequent elongation and shortening obtained by applying or releasing an equal load.

The initial instantaneous elongation is therefore partially elastic and partially permanent and may be regarded as one aspect of work hardening.

These experimental facts concerning interruptions in the creep test lead to the following practical applications:

After partial unloading from a value F to a value f, the rate of elongation is less than if the load f had been applied since the beginning. One could imagine some sort of "work hardening" of the creep rate by viscous deformation. It should therefore be possible to set loads F and f at such values that the rate after partial loading would be very slow, and would remain so for a considerable length of time, thus attaining practical stabilization of dimensions under the residual load f.

ALBERT PORTEVIN

Heat Treating Furnace
lined with stainless sheet

CLEVELAND, OHIO

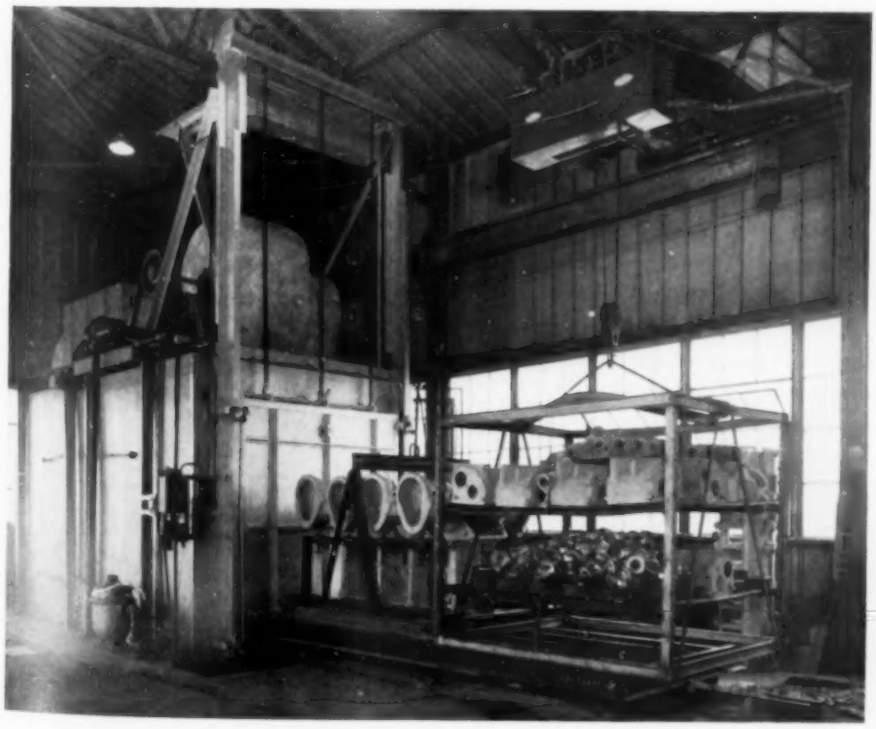
To the Readers of METAL PROGRESS:

NATIONAL DEFENSE has so stimulated the use of aluminum and magnesium alloy castings, as well as their size and diversity, that some information about how we are heat treating this additional load of production may be generally interesting. This firm, the National Bronze & Aluminum Co., with long and extensive experience in the sand casting of aluminum, was well acquainted with the necessity for proper heat treatment of these alloys, and experienced in its practical execution. A rapidly expanding output in at least four different alloys required that we enlarge our heat treating facilities with furnaces that have ready and scientific control of heat treating cycles, and positive assurance of uniform temperatures within the heating chamber.

After a broad survey and thorough deliberation regarding the type of furnace and fuel, our technical staff decided on a furnace of the type illustrated below, made by Despatch Oven Co. On its roof may be seen a gas-fired air heater, which employs radiant tubes. This installation is of the "surface" type, that is, the recirculating air is not in contact with or contaminated by the heating flames.

The effective heat treating chamber measures 7 ft. wide by 8 ft. high by 15 ft. long. It has a potential capacity of 10,000 lb. of aluminum castings per charge, with a maximum operating temperature of approximately 1200° F. The heat treating cycle varies with the different alloys; however, 6 hr. is required to bring furnace and charge "from cold to temperature", and 12 to 18 hr. is deemed necessary "at temperature".

The furnace itself is somewhat unusual in construction. It was erected in our plant very quickly of panels, completely pre-fabricated in the maker's shops. The walls are lined inside with 18-8 stainless steel, outside with plain carbon steel sheet, and between is 8 in. of high duty insulation. "Through metal" is avoided to prevent channels for heat escape. Telescopic joints, panel to panel, allow for thermal expansion, yet insure a



Furnace for Heat Treating Light Metal Castings. Push-button stick, hanging in front of building column at extreme right, controls electrically all motions of furnace door, car body, and overhead crane. Furnace is erected of pre-fabricated panels, lined with stainless steel sheet and heated by recirculating air (heater and fan on furnace roof). Courtesy Despatch Oven Co.

tight chamber. Heated air from the outside "firebox", as perhaps the heater can be called, is distributed through dozens of ducts within the furnace walls and floor, and discharged at the velocity of a high gale into the heating chamber at appropriate places directly against the load of work. There is an adjustable slide damper for each discharge port. Recirculation ducts leading spent air to the "firebox" are built into the furnace — all these ducts being of 18-8.

Since no combustion gases enter the furnace chamber proper, all types of aluminum alloys as well as magnesium castings can be properly and safely heat treated. Normally atmospheric air is the circulating medium, although a special protective atmosphere can also be employed. Hot air is quite suitable for such important alloys as No. 43 (5% Si); No. 195 (4% Cu) used for high strength parts of aircraft structures; No. 355 (1.3% Cu, 5.0% Si, 0.5% Mg) air engine crankcases; and No. 356 (7.0% Si, 0.3% Mg) structural fittings.

This convection furnace lends itself readily to uniformity of heat distribution as well as wide flexibility. Our tests prove that a temperature differential of plus or minus 5° F. is consistently attained and that castings ranging in weight from 1 oz. to 4500 lb. can be heat treated simultaneously with equally satisfactory results.

Although of only secondary importance in this particular instance, the fuel cost is nevertheless quite a significant factor. An average fuel consumption for a period of two months of scheduled operation is approximately 9000 cu.ft. of natural gas per net ton of charge.

More recently, another furnace with the same dimensions and general construction but equipped with a gas-fired direct recirculating type of air heater has been installed and is now in operation. In this furnace the gas flames blow directly into the recirculating air, which, of course, gradually builds up to a constant small amount of the gaseous products of combustion (principally CO_2 and H_2O). Tests reveal that the previously mentioned aluminum alloys can be heat treated with equally satisfactory physical properties as are being obtained in the first furnace; the only difference now perceptible is that alloys No. 355 and 356 have a somewhat darker coloration. Fuel consumption per charge has been decreased to an indicated 7145 cu.ft. per ton, as shown by a one-week test.

FRANK SCHMELLER
Plant Manager
National Bronze & Aluminum Co.

Controlled Atmosphere Generators

MASSILLON, OHIO

To the Readers of METAL PROGRESS:

IN THE ARTICLE on controlled atmosphere equipment, by Messrs. SLOWTER and GONSER, in the May issue of METAL PROGRESS, the erroneous impression may have been given that the atmosphere produced in the "Char-Mo" type unit was in true equilibrium with the carbon in the steel being heat treated. It will be recalled that, in this furnace setting, a container of charcoal is placed, and through this charcoal (heated to the same temperature as the muffle containing the work) is drawn some air to produce an atmosphere of CO and N_2 having also a small amount of H_2 and CO_2. The authors state:

"Its basic principle is that an atmosphere in equilibrium with carbon at a given temperature will be non-decarburizing (and non-oxidizing) to any steel *at the same temperature.*"

As a matter of fact, true equilibrium exists only in the special instance of a steel saturated with carbon at the temperature of heat treatment, and this can be shown both theoretically and practically. An atmosphere so generated is always carburizing to a steel unsaturated in carbon (above about 1400° F.).

The theoretical proof can be seen from a consideration of the equilibrium relationships involved. For the general reaction

$$C + CO_2 \rightleftarrows 2CO,$$

the equilibrium constant, K_T, is defined by the following equation:

$$K_T = \frac{P_{CO}^2}{A_C \cdot P_{CO_2}}$$

where P_{CO} and P_{CO_2} are the initial pressures of carbon monoxide and carbon dioxide respectively, and A_C is the activity of carbon. If the carbon is in the pure state (as charcoal in the producer unit), the activity A_C is unity. If the carbon is in solution in the steel, however, the activity becomes less than unity, and is approximately proportional to the dilution. Writing the constant in the form in which it is usually found in text books, namely

$$K'_T = K_T \cdot A_C = \frac{P_{CO}^2}{P_{CO_2}}$$

one can see that K'_T, and therefore the propor-

(Continued on page 224)

Crystallography of the Chemical Elements

As Tabulated by William Hume-Rothery
in "The Structure of Metals and Alloys," Monograph No. 1, British Institute of Metals.

Emendations (by H.C. Vacher) represent values that have appeared in the literature from 1936 to 1940 inclusive.

Element Atomic No.	Electron Arrangement in Free Atoms	Crystal Structure (Note a)	Axial Ratio c÷a	Coordination No.	Lattice Constant a	Lattice Constant c	Interatomic Distance d_1	Interatomic Distance d_2	Atomic Diameter Coordination No. 12 (Note f)	Reference (g)
Group VII A in Periodic Sequence										
25, Manganese	[2][8][13] 2	α = cubic (note b)	—	—	8.894	—	—	—	—	—
		β = cubic (note c)		12	6.300	—	—	—	—	—
		γ = △	0.934	—	3.774	3.526	2.582	2.669	—	—
43, Masurium	[2][8][18][14] 1	—	—	—	—	—	—	—	—	—
75, Rhenium	[2][8][18][32][18] 2	○	1.6148	—	2.7553	4.4493	2.7349	2.7553	2.75	—
Group VII B										
9, Fluorine	[2]7	—	—	—	—	—	—	—	—	—
17, Chlorine	[2][8]7	△	0.715	—	8.56	6.12	1.88 (note e)	—	—	4
			16 atoms in unit cell							
35, Bromine	[2][8][18]7	▯	a:b:c = 1:1.49:1.95		4.48	8.72	2.27	noted	—	5
			8 atoms in unit cell; b = 6.67							
53, Iodine	[2][8][18][18]7	▯	a:b:c = 1:1.51:2.04		4.795	9.780	2.70	noted	—	—
			8 atoms in unit cell; b = 7.255							
85, Alabamine	[2][8][18][32][18]7	—	—	—	—	—	—	—	—	—
Group VIII in Periodic Sequence										
26, Iron	[2][8][14] 2	α = ⧉	—	—	2.861	—	2.477	—	—	—
		β = ⊡	—	—	3.64 at 900°C.	—	2.58	—	2.52	—
27, Cobalt	[2][8][15] 2	α = ○	1.624	—	2.507	4.072	2.499	2.507	2.50	—
		β = ⊡	—	—	3.545	—	2.507	—	2.507	—
28, Nickel	[2][8][16] 2	α = ○	1.64	—	2.49	4.08	2.49	2.49	2.49	—
		β = ⊡	—	—	3.517	—	2.486	—	2.487	—
44, Ruthenium	[2][8][18][15] 1	○	1.583	—	2.698	4.273	2.644	2.698	2.67	8
45, Rhodium	[2][8][18][16] 1	⊡	—	—	3.795	—	2.683	—	2.684	—
46, Palladium	[2][8][18][18]	⊡	—	—	3.882	—	2.745	—	2.745	—
76, Osmium	[2][8][18][32][14]2	○	1.579	—	2.729	4.310	2.670	2.730	2.70	8
77, Iridium	[2][8][18][32][15] 2	⊡	—	—	3.831	—	2.709	—	2.709	—
78, Platinum	[2][8][18][32][16] 2	⊡	—	—	3.915	—	2.768	—	2.769	—
Rare Earth Group										
58, Cerium	[2][8][18][19][9]2	α = ○	1.62	6,6	3.65	5.91	3.63	3.65	3.64	—
		β = ⊡	—	12	5.143	—	3.637	—	3.637	—
59, Praseodymium	[2][8][18][20][9] 2	○	1.620	6,6	3.657	5.924	3.638	3.657	3.65	—
60, Neodymium	[2][8][18][21][9] 2	○	1.608	6,6	3.657	5.88	3.619	3.657	3.64	—
67, Holmium	[2][8][18][28][9] 2	○	1.580	6,6	3.557±3	5.620±5	3.480	3.557	3.52	11
68, Erbium	[2][8][18][29][9]2	○	1.63	6,6	3.74	6.09	3.73	3.74	3.73	—

Notes: (a) ⧉ is body-centered cubic; ⊡ is face-centered cubic; ○ is close packed hexagonal; ▯ is orthorhombic; △ is tetragonal.

(b) Approximates ⧉ where each lattice point is a cluster of 29 atoms; 1 type X, 4 type A, 12 type D_2 and 12 type D_1. The X atoms occupy the largest volume and the D_2 the smallest. Interatomic distances of neighboring atoms are as follows:

X atoms have: 12 D_2 at 2.71; 4 A at 2.82

A atoms have: 1 X at 2.82; 3 D_1 at 2.49 and 3 at 2.96; 3 D_2 at 2.69 and 3 at 2.89

D_2 atoms have: 1 X at 2.71; 2 A at 2.69 and 1 at 2.89; 1 D_2 at 2.24 and 2 at 2.38; 1 D_1 at 2.45, 2 at 2.51 and 2 at 2.66

D_1 atoms have: 1 A at 2.49 and 1 at 2.96; 1 D_2 at 2.45, 2 at 2.51 and 2 at 2.66; 6 D_1 at 2.67

(c) Complicated structure with 20 atoms of two kinds in unit cell. Each atom of the first kind has:

3 neighbors at 2.365
3 " " 2.530
3 " " 2.671
3 " " 2.675

Each atom of the second kind has: 2 neighbors at 2.530
2 " " 2.615
4 " " 2.659
2 " " 2.671
2 " " 2.675

(d) Atoms arranged in pairs so that each one has one close neighbor at a distance d_1.

(e) The authors give 1.99 as the closest approach to a neighboring atom, however, they did not indicate clearly the space group. If the space group is D_{4h}^{16} with 16 atoms to a unit cell and the X, Y, and Z parameters are 0.125, 0.167 and 0.107, respectively, then $d_1 = 1.88$.

(f) Atomic diameters for new values have been computed by following Hume-Rothery's procedure whenever possible.

(g) See Page 580, Metal Progress, May 1941.

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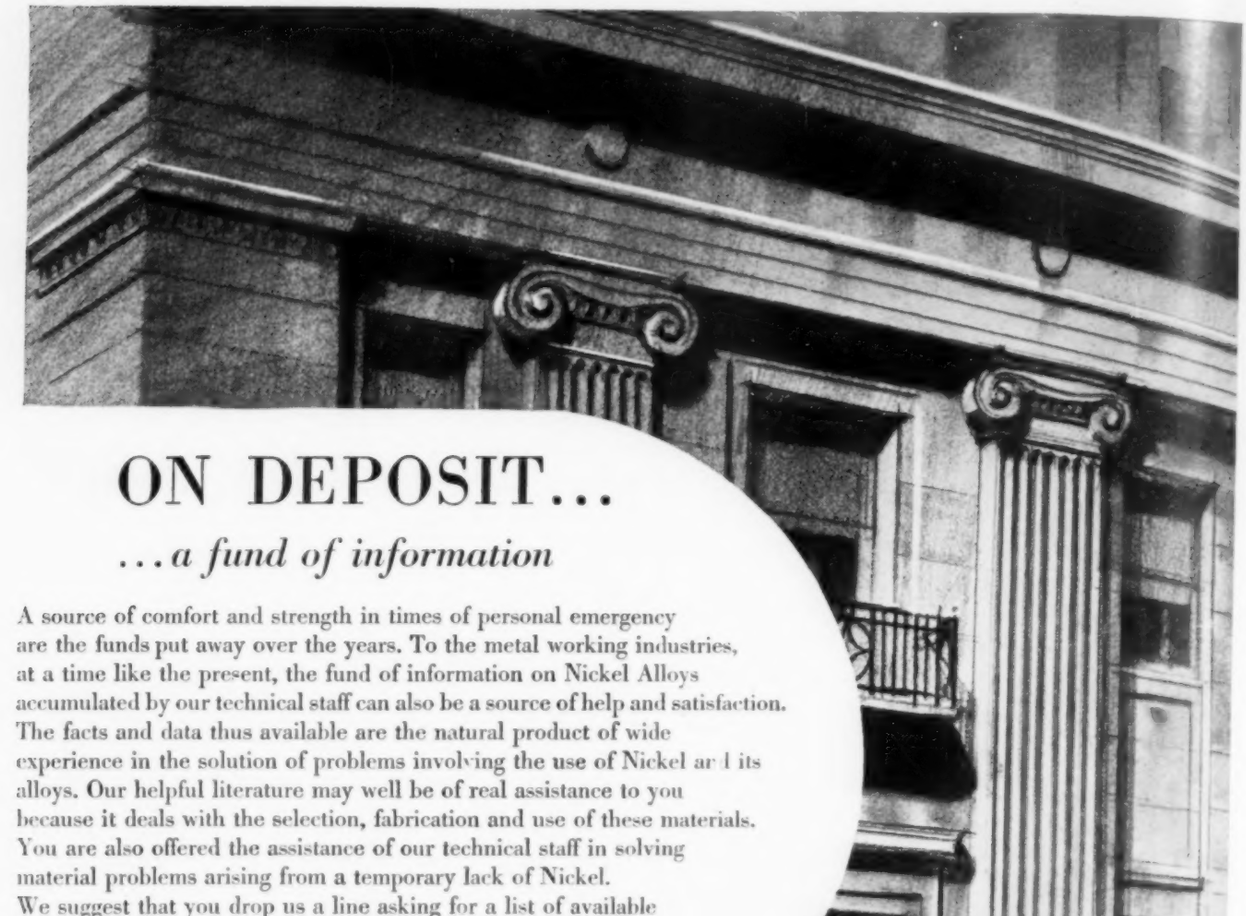
METAL PROGRESS



ON DEPOSIT...

...a fund of information

A source of comfort and strength in times of personal emergency are the funds put away over the years. To the metal working industries, at a time like the present, the fund of information on Nickel Alloys accumulated by our technical staff can also be a source of help and satisfaction. The facts and data thus available are the natural product of wide experience in the solution of problems involving the use of Nickel and its alloys. Our helpful literature may well be of real assistance to you because it deals with the selection, fabrication and use of these materials. You are also offered the assistance of our technical staff in solving material problems arising from a temporary lack of Nickel.
We suggest that you drop us a line asking for a list of available literature. Your request for the assistance of our technical staff will receive prompt attention.

NICKEL

THE INTERNATIONAL NICKEL COMPANY, INC. 67 WALL STREET NEW YORK, N. Y.

Fig. 1 — Fatigue Failure of Arch Bar Originating in Three Punch Marks

RAILROAD FAILURES

in track

and cars

By Ray McBrian
Engineer of Tests
and P. A. Archibald
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RAILROAD LABORATORIES frequently encounter problems peculiar to the railroad business, but usually their solution lies in the application of general principles of engineering design, mechanics, and metallurgy. For example, the use of the microscope, chemistry, physical tests, and photo-elastic study, are sufficient tools to aid in the study of most failures. Material failures in general are due to any one or combination of the following factors: Poor design, defective material, improper application, faulty fabrication, and abuse in service. The following examples from the Rio Grande Laboratory files illustrate the application of these principles.

Arch Bar Failure

Figure 1 is the fracture of an arch bar which failed and caused an expensive derailment. This part is a component of the side frame of a car truck; it is a stout rectangular bar, bent into a "U" shape so that it passes over and under the wheel bearings and spring housings to transmit the loads from springs to axles. In service the bar is subjected to a bending moment and axial tension; normally there is little or no torsion.

Only a casual inspection of the fracture

was necessary to show that failure was caused by a fatigue crack, the result of three separate fatigue cracks originating at dents in the surface. These dents proved to be prick-punch marks put there by the blacksmith to mark the location for the bend when the arch bar was heated and formed into its "U" shape. These marks, clearly seen in the engraving at the head of this article, were stress raisers and were located in a highly stressed area. The resulting concentration of stress at these three points exceeded the endurance limit of the bar and a disastrous fatigue failure resulted.

Fig. 2 (below) — Cracks in Joint Bar Outlined by White Magnaflux Powder

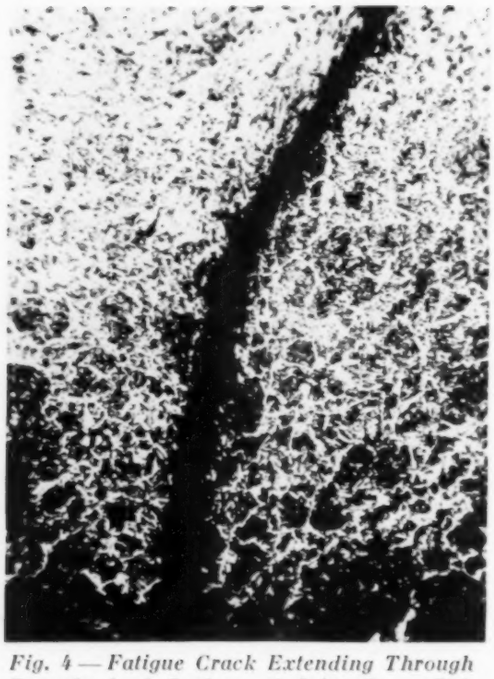


Fig. 4 — Fatigue Crack Extending Through Decarburized Surface of Joint Bar. Polished, etched and magnified 100 diameters

Joint Bar Failure

The second figure is a photograph of the upper contact surface of a joint bar (or splice bar) showing a transverse crack outlined with white magnaflux powder.

As is well known, joint bars are used in pairs, one on each side of the rail joint, and are

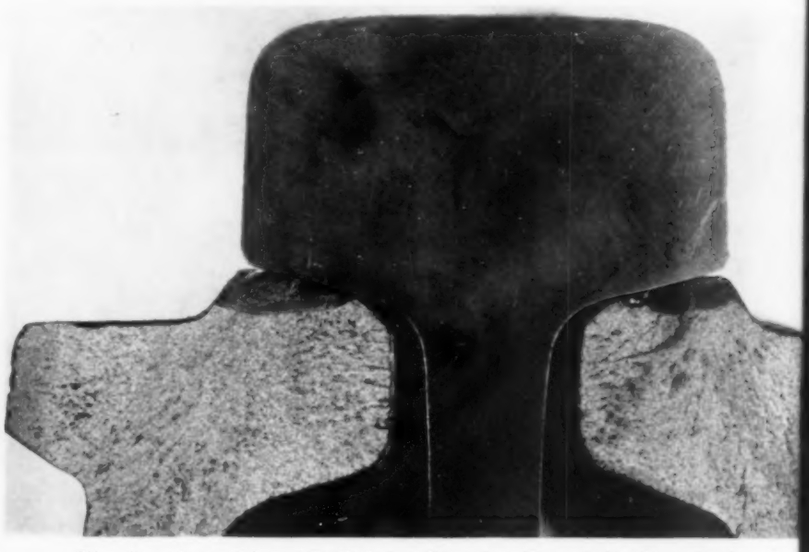


Fig. 3 — Assembly at Rail Joint Showing Two Joint Bars Broken at Places Marked by Rusty Fatigue Cracks Starting at Upper Contacts

strongly bolted together to hold the ends of adjoining rails in line and also to support the joint against its lateral and vertical loads.

Figure 3 is a photograph of a rail joint assembly showing two similarly cracked bars with the cracks at the contact surface as they occur in service.

Photo-elastic study showed that the intended surface contact between under side of rail head and upper side of joint bar was not easily obtained. Actually the bearing, each to each, was more like line contact than surface contact, and there existed an extremely high concentration of stress at the line of contact when a car or engine wheel passed from one rail to the next. Microscopic examination of samples from a large number of bars disclosed various amounts of decarburization at the contact surface. Figure 4 is a photomicrograph at 100 diameters showing a crack extending through one of these decarburized surfaces. The curvature of the crack is due in part to the flow of metal at the surface from the gouging action of the rail end as the joint flexes under wheel loads.

Failure of these joint bars was therefore attributed to faulty design and surface decarburization. The joint was not designed so as to provide the proper contact

surface; this resulted in a strong concentration of stress. Decarburization of the steel at the surface meant that the material was weakest at the point subjected to the highest load. A new contour has been designed for the splice bars that insures (almost forces) assembly in track so there is generous bearing between rail and splice bar, and a specific load that is safe.

The problem of decarburized surface on commercial steel articles is by no means confined to the railroad purchases, and is as yet unsolved. Crown sheet failures and broken staybolts have become epidemic, and one associated cause is that the steels, as received from the mills, always have a thin decarburized (weak) surface.

Fig. 5 — End Broken From Car Axle; Fracture Was Alongside the Wheel Seat

Below: Microstructure of "Burned" Metal Near Journal Surface

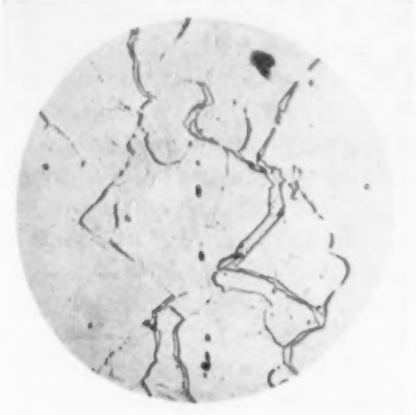


Fig. 6 — Unetched

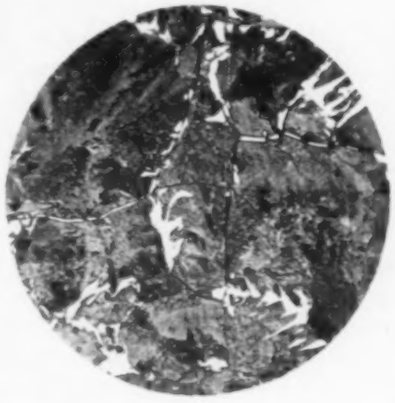


Fig. 7 — Etched With Nital

Axle Failure

Figure 5 is a photograph of the end, broken off an axle. The failure was in the journal (or bearing) just beyond the wheel seat.

The broken section had every appearance of having been extremely hot but there was no evidence of a fatigue crack or defect. Samples from the axle examined on the microscope revealed a "burned" structure reproduced in Fig. 6, unetched, and Fig. 7, etched in nital, at 500 diameters.

This structure gave indisputable proof that the journal had become severely overheated, as was suspected by the appearance of the journal's surface. At the high temperature the steel had low physical properties and the normal bending and torsional stresses were sufficient to twist it off. This failure resulted from a "hot box".

This case emphasizes the seriousness of bearing failures. One might not suspect that sufficient heat could be generated in such a friction bearing as to actually "burn" the steel.

The maximum benefits from investigations of this kind are derived only when they are followed up with appropriate steps to prevent a recurrence. When design is under suspicion the investigation should be supplemented with stress measurements or photo-elastic study, in order to devise a new shape which will distribute the load-carrying capacity with respect to the actual stresses. If the material lacks sufficient strength, stronger materials must be sought. If the failure is due to faulty fabrication or unnecessary abuse the necessary corrections must be made. Cooperation of shop men is better than some would have us believe.

ANNEALING OF MONEL

details of practice

By Technical Service Division
The International Nickel Co., Inc.
New York City

A DEFINITION of "annealing" occupies almost a page in the authoritative Metals Handbook starting out with this: "A heating and cooling operation implying usually a relatively slow cooling." It is obviously a comprehensive term, and in practice is usually applied to operations intended to soften the metal. Usually this is the result of a partial or complete recrystallization. In this paper the several ordinary types of annealing heat treatments as applied to high nickel alloys will first be described, and then some general notes on the correct shop practices appended.

Soft Annealing

Metals and alloys which have been hardened by cold working operations, such as rolling, deep drawing, spinning, severe bending, and the like, require softening before cold working can be continued. The thermal treatment which will produce this condition is known as "annealing" or "soft annealing". Soft annealing can either be done with the work exposed to the furnace atmosphere, when it is known as "open annealing", or enclosed in protective boxes, "closed annealing" or "box annealing". In any event the atmosphere should be free of harmful sulphur, and oxidation kept at a minimum. Means for achieving both these objectives will be discussed later.

Open Annealing — Relationships between temperature and time for open annealing are shown in Fig. 1 and 2 for Monel metal. "K" Monel and "R" Monel require the same temperature as Monel. However, "K" Monel is a precipitation hardening alloy and must be cooled rapidly (quenched) after annealing if maximum softness and subsequent response to age hardening are desired. Details of this treatment will not be discussed in this article. (The names Monel, "K" Monel, "R" Monel, and Inconel are registered in the U.S. Patent Office.)

Figures 1 and 2 apply to single pieces of material in the furnace. If pieces are stacked or are shadowed by other pieces, this must be allowed for in determining both the time the work should remain in the furnace and the annealing temperature, in order to avoid a coarse-grained structure.

For example, a single piece of hard Monel metal sheet must be annealed to Rockwell B-68 so as to be suitable for further spinning operations. The furnace temperature available is 1600° F. The 1600° F. curve in Fig. 1 shows that this degree of softness can be obtained in 4 min. at temperature. Figure 2 shows further that the time must not be allowed to exceed 9 min. if a fine grain is necessary, or 17 min. if a medium grain is desired.

The material to be annealed is heated at the selected temperature, and protected from

oxidation by the products of combustion in a fuel-fired furnace, or by a reducing gas introduced into an electric furnace. The furnace should be "at temperature" before the work is charged into it. During preliminary heating of a fuel-fired furnace, the burners may be adjusted to give optimum combustion, but before charging, the air supply should be reduced to give the excess of reducing gases required. Also, the top vents or dampers should be closed wholly or partially to give a positive gas pressure over the hearth and thereby prevent infiltration of air.

Some classes of work, particularly pieces for spinning, call for softer annealing than others. The more severe the nature of the subsequent cold working the longer must be the time at temperature. Periods ranging from 5 to 10 min. at 1600° F., to 1 to 4 min. at 1800° F., are sufficiently broad to provide a satisfactory latitude in handling the work in and out of the furnace. The shorter periods do not yield full softness but will condition the metal for operations such as capping, drawing, stamping and the like.

Dead-Soft Annealing — When the high nickel materials are annealed at higher temperatures and for longer periods than those recommended, a condition commonly described as "dead-soft" is obtained. Hardness numbers will then be 10 to 20% lower than those for the "soft" condition. This cannot be accomplished without increasing the grain size of the material. Therefore, it should be used only for those few purposes for which grain size is of little importance.

Articles for drawing and spinning operations, and the like, never should be annealed dead-soft since this will produce a coarse grain. Heavy plate sections and thick-walled tubing that are required only to negotiate certain bending operations may be annealed dead-soft to facilitate working because the coarse grain produced thereby would not affect service adversely.

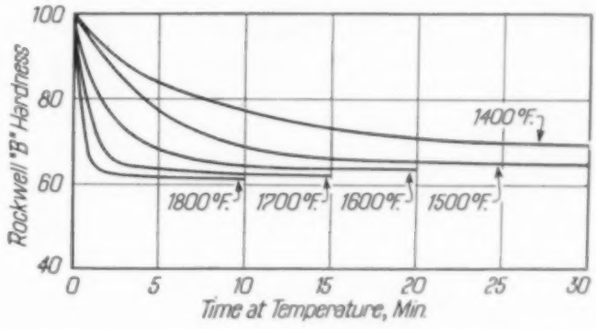


Fig. 1, above — Relations Between Time and Temperature Necessary to Soften Monel Metal, Cold Worked to B-100 Hard

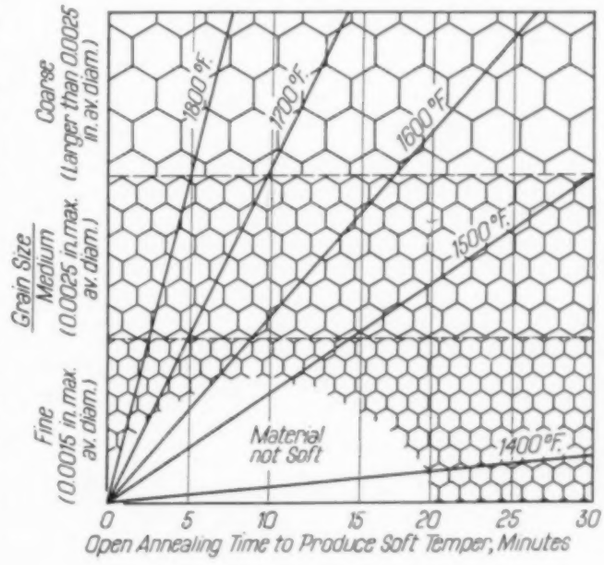


Fig. 2, at left — Annealing at 1700° F. Will Soften Cold-Worked Monel Very Quickly (as Shown in Fig. 1); Long Times Must Be Avoided to Prevent Grain Growth

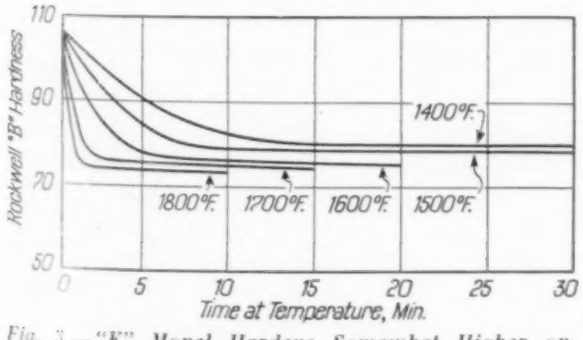


Fig. 3 — "K" Monel Hardens Somewhat Higher on Cold Work Than Regular Monel, and Its Softness After Appropriate Heatings Is Correspondingly Higher

Closed (box) annealing requires more time than open annealing because of the lower temperatures used; temperature control is therefore less critical. The heavy container itself must be heated to a slightly higher temperature than that required for the work, so that the amount of fuel required, the heating time and the cost are greater than in open annealing. Consequently, box annealing is usually limited to small pressed parts, rivets, coiled wire and similar work because of greater ease in handling in quantity.

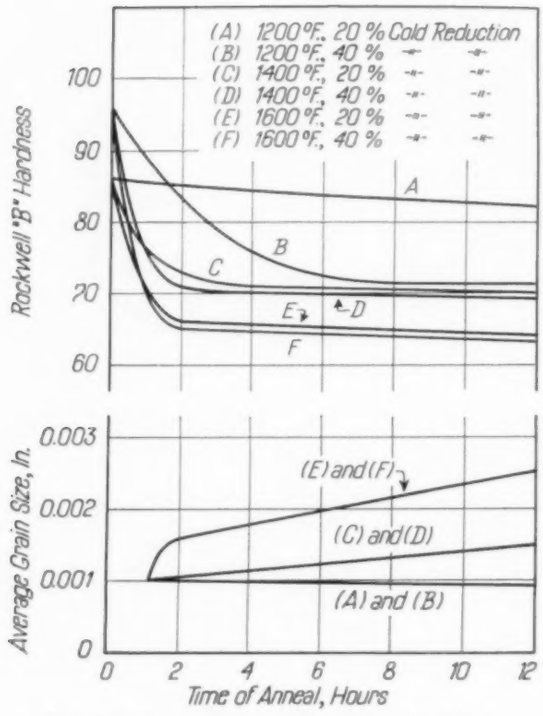


Fig. 4 — Approximate Time Required for Closed Annealing at Various Temperatures to Produce Different Grain Sizes and Degrees of Softness in Cold-Worked Monel

Monel, box annealed in the temperature range between 1600 to 1750° F., would ordinarily result in a coarse grain; from 1450 to 1600° a medium grain; from 1300 to 1450° a fine grain. Lower temperatures and long times would also give some softening effects. In all cases the time and temperature are interrelated with the previous degree of cold work, as shown in Fig. 4.

Temper Annealing (or partial annealing)

The process of heating a hardened metal or alloy at a temperature and for a period sufficient merely to soften it partially is defined as "temper annealing", "semi-annealing" or "partial annealing".

The practice is limited to light sections — usually strip and wire. It has value for operations where fully annealed material is not required. Any method of annealing may be used, although the continuous method is best suited. Careful regulation of the time at temperature is essential. As an example a cold-drawn Monel rod, B-100 hard with 20% elongation, will be B-91 hard and have 37% elongation after 3 hr. at 1110° F.

Stress Equalizing

Cold-worked and hot-worked alloys require a low temperature heat treatment to develop the optimum combination of strength and ductility, and to prevent distortion and warping upon subsequent machining. The proper temperature depends upon the nature of the preliminary fabrication or working; hot-worked material requires a higher temperature than cold-worked.

The optimum temperature is about 525 to 575° F. for cold-worked Monel. Long exposures at these temperatures are not harmful. For instance, the 40,000-psi. proportional limit of a 1-in. rod, cold drawn 20%, was increased to 82,000 psi. by heating at 525° F. for 1 hr. This figure stayed as high as 80,000 psi. after a 16-hr. heating.

Monel and "K" Monel springs are made from heavily cold-drawn wire or cold-rolled strip. They should be stress equalized after coiling. The preferred annealing treatment is 1 hr. at 650° F.

For hot-rolled ¾-in. Monel plate the optimum stress equalizing temperature is from 1000 to 1100° F.

Special Methods

Torch Annealing — Some large equipment is hardened locally by the fabricating operations. If the available annealing furnace is too small to hold the work, the hardened sections can be annealed with the flames of oil torches or oxy-acetylene blowpipes which have been adjusted so as to be highly reducing. This method is not a good one for general use because it gives irregular and insufficient annealing, with heavily oxidized surfaces.

Heating must be gradual. Use temporary brick construction to localize the heat. The work should be warmed gently at first, with sweeping motions of the torch, and should not be brought to the annealing temperature until preheated sufficiently to prevent cracking when the stresses are suddenly and perhaps unevenly released.

Salt bath annealing is used for small parts. Inorganic salts, such as chlorides and carbonates of sodium and potassium, which are relatively stable at temperatures considerably above their respective melting points, are melted or fused in large metallic containers by any convenient source of heat. Steel pots are satisfactory containers for salts operating at temperatures up to about 1300° F. At higher temperatures heat resisting nickel-chromium-iron alloy pots should be used. Excessive fuming of the bath is an indication of its maximum usable temperature.

Particular care must be exercised initially to remove all traces of sulphur from the fused salts and thereby prevent embrittlement of the high nickel alloys. This may be accomplished in 2 to 3 hr. by adding a small amount of a 75:25 mixture by volume of powdered borax and powdered charcoal. If small test pieces of Monel strip or wire are not embrittled after 3 or 4 hr. in the purified salt bath, the desulphurizing treatment has been successful.

The material to be annealed is placed in the molten bath and absorbs heat rapidly. The work is quenched in water to free it from particles of salt. It will not be bright and must be flash pickled. Salt mixtures may be formulated according to Metals Handbook, page 317, or (better) purchased from a manufacturer of heat treating supplies.

Electrical resistance annealing is also a special method wherein an electric current is passed through the material to be annealed, which acts as a resistor and is heated rapidly.

The method has seldom been satisfactory. Temperature control is difficult unless the material is uniform in size and it is extremely difficult to provide a suitable reducing atmosphere for bright annealing. The results are irregular.

Bright Annealing

Hot metals and alloys will not become oxidized in an atmosphere that is free from uncombined oxygen and gaseous compounds of oxygen. If the gases are such as to abstract oxygen from any solid oxides they come in contact with, it is a "reducing" atmosphere. The maintenance of an oxygen-free, or reducing, atmosphere during annealing and subsequent cooling may be effected as follows:

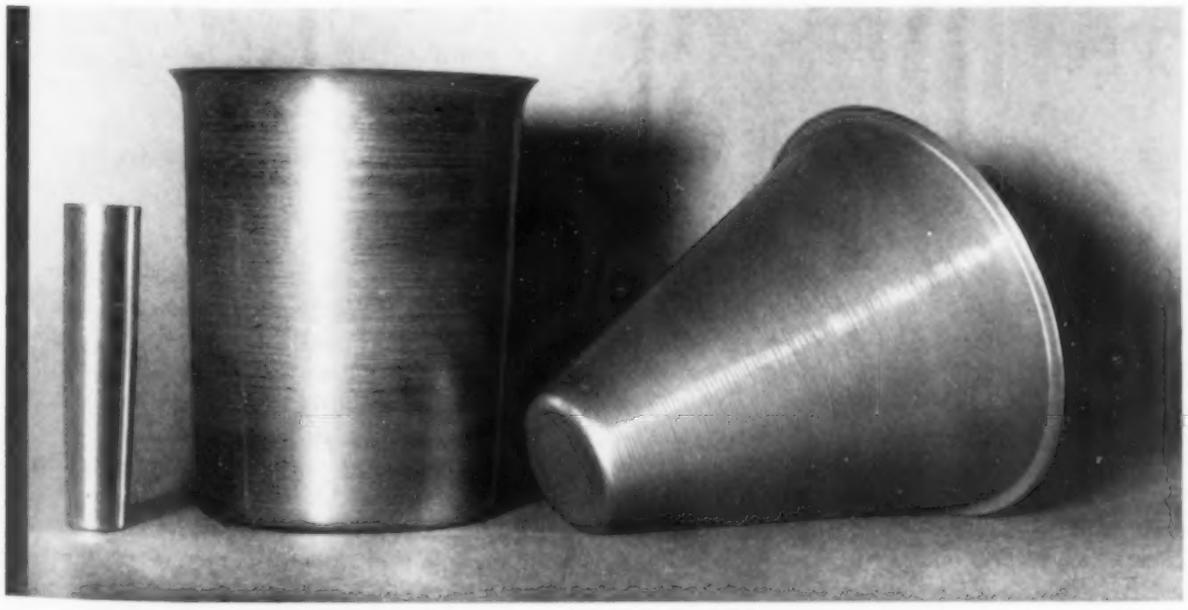
1. By regulating the fuel and air supplies so as to secure incomplete combustion.
2. By introducing a reducing gas, such as hydrogen or carbon monoxide, or a mixture of a reducing gas and an inert gas, such as hydrogen and nitrogen, into the combustion chamber.
3. By having some incandescent charcoal in the furnace. (Charcoal always should be pre-baked for 3 hr. at 1200 to 1500° F. to eliminate adsorbed moisture and carbon dioxide.)

Bright annealing eliminates subsequent pickling or grinding. For that reason it is used generally for non-ferrous materials.

Monel and high nickel alloys (except Inconel, which contains chromium) differ from steel in that they can be bright annealed in reducing atmospheres containing appreciable amounts of water vapor and carbon dioxide.

Theoretically, open annealing can also be bright annealing, and if this is attempted, extra attention must be given to the fuel. High nickel alloys are sensitive to attack by sulphur at annealing temperatures and more so in reducing than in oxidizing atmospheres.

Natural gas (sulphur-free), hydrocarbons



When Heavy Work Is to Be Done on Sheet Metal (as in Spinning These Deep Cups From a Round Disk) it Is Well to Discuss the Work With the Sheet Manufacturer so he Can Supply Metal of Proper Grain Size and Temper

such as methane, propane, butane, are ideal sources of heat, as well as electricity.

City gas, light distillate oils and other liquid or gaseous fuels having 0.5% maximum sulphur are suitable fuels when provisions are made in the design and construction of the furnace to effect *complete* combustion before the hot gases strike the metal. City gases usually contain less than 0.1% of sulphur, but it may vary from day to day so that frequent tests are necessary.

Fuel oils, coal or coke, which contain more than 0.5% sulphur, are not suitable fuels except when the material that is being annealed is protected completely from contact with the products of combustion. This limits such fuels to box or pot annealing or to a source of heat for molten salt or molten metal baths.

Atmospheres

The required degree of control of the furnace atmosphere will depend upon the results desired. Naturally, bright annealing can be done only in the absence of all oxidizing influences. On the other hand, a superficial tarnish or oxide coating is often permissible, as for parts that are to be polished after annealing, or that do not require a perfectly clean surface for subsequent fabricating operations.

Regardless of the use to which the finished articles are to be put, high nickel alloys should *never* be annealed in a strongly oxidizing atmosphere. Heavy oxide coating may harm the underlying material even though the oxide is removed by grinding or pickling.

Suitable atmospheres for bright annealing include hydrogen, cracked ammonia, nitrogen, cracked and sulphur-free natural or city gas, cracked hydrocarbons, or a generated atmosphere containing some combination of carbon monoxide, carbon dioxide, hydrogen, nitrogen and hydrocarbons. Propane or butane should not be used unless the formation of soot can be prevented or unless the soot is filtered out.

Sulphur occurs usually in manufactured gases as hydrogen sulphide and occasionally as carbon disulphide. The former can be removed by passing the gas through a series of boxes containing a mixture of hydrated iron oxide and shavings. Removal of carbon disulphide is more difficult and requires hydrogenation to hydrogen sulphide and removal as above.

Since prepared atmospheres are expensive they are usually confined inside boxes or other containers with the hot work to be protected.

For perfectly bright annealing, dry hydrogen is the most desirable atmosphere. Cracked and dried ammonia also is suitable. Hydrogen gas and liquid ammonia, supplied in cylinders, should be of the purest commercial grade available. The gas line from the cylinder should contain a reducing valve of good sensitivity for accurate regulation of the flow.

Traces of oxygen can be removed from hydrogen by passing the gas through copper chips, heated externally to 1250° F. The copper will act as a catalyst to combine the oxygen with an equivalent amount of hydrogen to form water vapor that can then be removed, along with any water vapor originally contained in the gas.

If ammonia is being used, either the cracking or the removal of oxygen may be carried out first. Ammonia will "crack" or break down into its components, hydrogen and nitrogen, when passing through a pipe externally heated to 1750° F. Commercial equipment for gas cracking is available.

Since the flow of gas will be very slow, the connecting pipe from the heater to the dryer usually will suffice to act as a cooling coil. Should this be insufficient to bring the gas back to room temperature, a coil may be inserted into

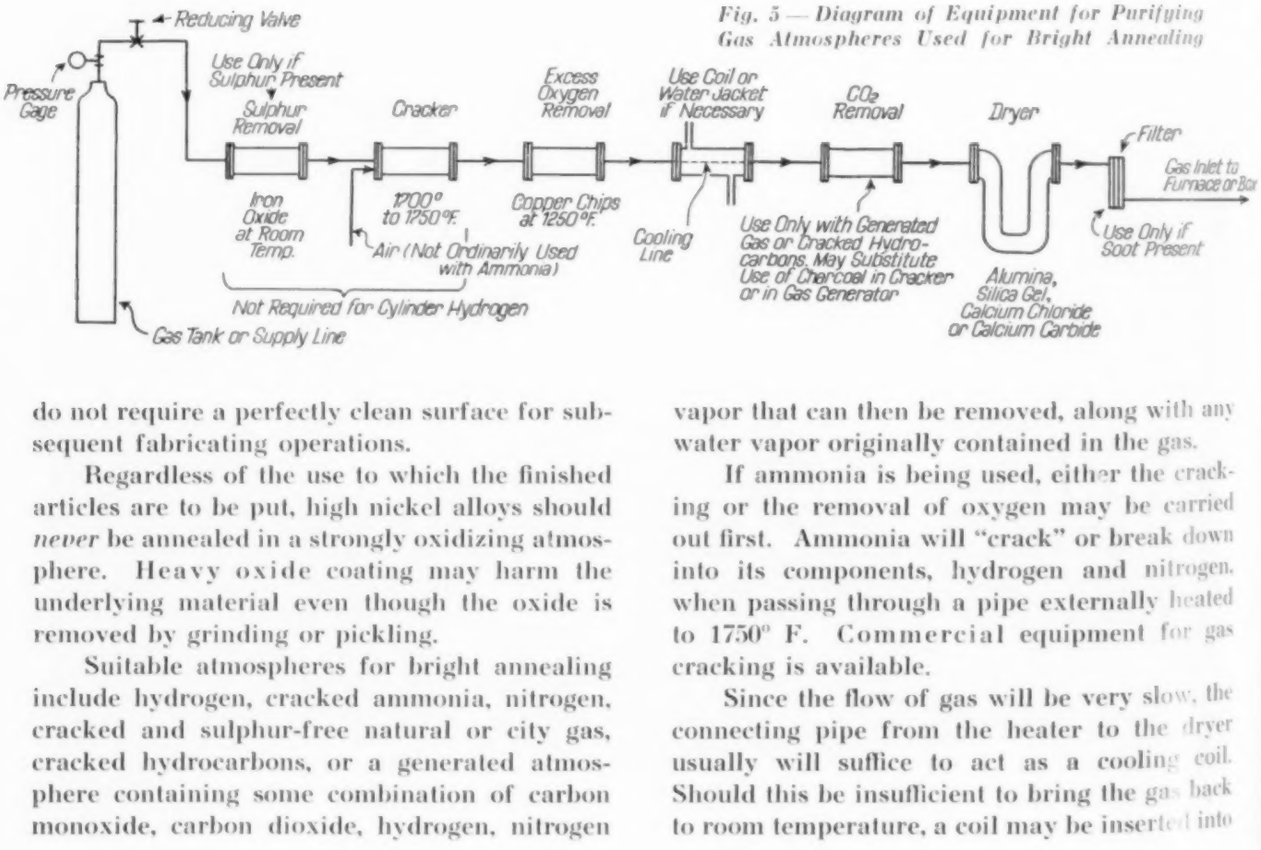
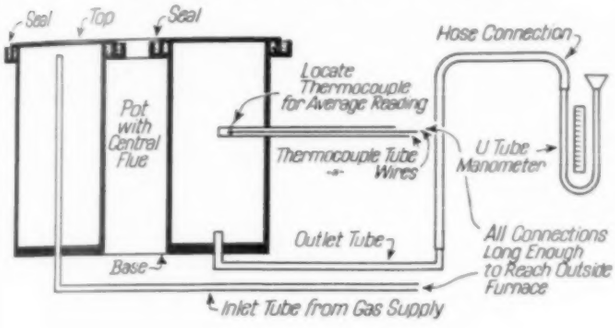

Reducing Valve
Pressure Gage
Use Only if Sulphur Present
Sulphur Removal
Cracker
Excess Oxygen Removal
Use Coil or Water Jacket if Necessary
CO_2 Removal
Dryer
Filter
Gas Inlet to Furnace or Box
Iron Oxide at Room Temp.
1700° to 1750°F.
Copper Chips at 1250°F.
Air (Not Ordinarily Used with Ammonia)
Cooling Line
Use Only with Generated Gas or Cracked Hydrocarbons, May Substitute Use of Charcoal in Cracker or in Gas Generator
Use Only if Soot Present
Alumina, Silica Gel, Calcium Chloride or Calcium Carbide
Not Required for Cylinder Hydrogen
Gas Tank or Supply Line

Fig. 5 — Diagram of Equipment for Purifying Gas Atmospheres Used for Bright Annealing

the line, or the line may be water jacketed.

For drying, the gas can be passed through activated alumina, silica gel, calcium chloride or other drying agents. The use of calcium carbide is rather undesirable when large amounts of moisture are to be removed, since the resulting acetylene would deposit soot on the charge. Clean hydrogen should never come in contact with rusted pipe lines, else water vapor will form.

Fig. 6 — Diagram of Annealing Box Assembly



Annealing Boxes

Annealing boxes may be made of steel, cast iron or preferably of a heat resisting alloy. A wide variety of shapes and sizes are used. Welded steel boxes usually are cylindrical in shape, with height equal to, or slightly greater than, the diameter. To secure more uniform and rapid heating, boxes should have a center flue half the diameter of the box, and placed on rails so as to provide good circulation of hot gases. Another good box has a flat, flanged bottom, on which the work is stacked, and an inverted cover or bell. This is often described as an "upside down" pot.

A tightly closed, electrically heated furnace may be looked upon as an annealing box, but ordinarily the work is stacked loosely in a movable container, the container sealed and put into a furnace for heating. A suitable thermocouple should be located about in the center of the charge, and led outside through gas-tight joints.

After the work has been charged, the boxes should be luted with fireclay or sealed with sand or other suitable refractory material. A small quantity of prebaked charcoal should be placed inside at points where air could enter.

Having a source of clean, dry, oxygen-free hydrogen, cracked ammonia, or other suitable combination of gases, and having eliminated possible formation of water vapor within the equipment, it is necessary to insure thorough purging of air and other undesirable gases from the heating box (or furnace chamber, if it is to be used as a box for bright annealing). Purge the container well before heating, to avoid explosive mixtures of gas with residual air.

Boxes can be safely and completely purged by the following steps:

1. Place the charge in the box, allowing ample space for the circulation of gas between the parts. See that the thermocouple is located properly in the middle of the mass.

2. Turn on the prepared atmosphere through the inlet tube. This tube ordinarily will extend into the box and have its end above the top of the load, as shown in Fig. 6. Light this flowing gas. Adjust the gas pressure for a flame of about 1½ in.; the flame will then burn against the top of the box.

3. Place the cover on the box and seal it thoroughly with sand or clay. The outlet tube at the bottom of the box should be left open, so hot air and products of combustion can escape.

4. When air has been removed completely, the flame will go out. This will become apparent by the fact that the hot spot on the box cover will cool.

5. Connect a manometer to the outlet without interrupting the flow of gas. The flow should then be regulated so that the manometer will indicate a positive box pressure of not less than 0.2 in. of water. Under this condition there will be a slow escape of gas bubbles through the water in the manometer tube.

6. The box may then be placed in the furnace and the annealing operation carried out.

An alternative method of regulating the pressure in the box is to light the gas escaping from the outlet tube instead of connecting it to the manometer. It will be necessary to have a flame of 1 to 2 in. in length and, in order to avoid wasting gas, the end of the line should be constricted by an orifice. This method is less reliable than the manometer method.

Reducing gas is continued in the box on withdrawing it from the furnace, or on shutting off the burners, else the cooling gas inside, on contracting, will create a partial vacuum and suck air through the seals. Following annealing the flow of gas should be regulated so as to maintain a positive pressure within the box; the gas, if it is combustible, will burn gently at all outlets. *(Continued on page 228)*

NO MORE FISSURES

in slowly cooled rails

By Thomas J. Dolan
Assistant Professor of
Theoretical and Applied Mechanics
Talbot Laboratory
Urbana, Ill.

THE SEVENTH progress report on fissures in rail presents a summary of ten years of research work conducted by the Engineering Experiment Station of the University of Illinois in cooperation with the manufacturers of steel rails and the Association of American Railroads in an attempt to determine the causes of transverse fissures in railroad rails and the methods of preventing this type of failure. This report is published in the 1941 *Proceedings* of the American Railway Engineering Association, and in Reprint No. 21 by the Engineering Experiment Station of the University of Illinois, Urbana. Summaries of the work have been published in METAL PROGRESS in 1935, 1936 and 1937 by Prof. H. F. MOORE, who has been supervising these researches.

The problem of internal transverse fissures had been prominently before rail makers and rail users since 1911, when a wreck on the Lehigh Valley railroad, ascribed to this cause, resulted in the death of 29 and the injury of 62 people. Despite study by both railroads and steel men, little real progress had been made in 15 years in the understanding and control of the defect, as may be inferred from the fact that an even more serious and distressing accident from the same cause occurred in 1925 on the St. Louis and San Francisco Ry.

However, WARING and HOFAMMANN had discovered in 1919 that some rails (both new and from the track) contained internal "shatter cracks", discoverable on longitudinal sections after deep etching. Prior to the inception of the studies at Urbana in 1931 and in the studies there, a great deal of evidence has been accumulated indicating that shatter cracks produced in the steel during the manufacturing process are the major cause of transverse fissures in rails in service. These very small shatter cracks occasionally found in railroad rails apparently are the same as, or at least very similar to, the widely discussed "flakes" sometimes found in alloy steel and heavy forgings. In some instances shatter cracks have also led to compound fissures and horizontal split heads in the rail. However, any other internal "stress raisers" in the head of the rail, such as large slag inclusions or blow-holes, may be equally effective in starting interior progressive fractures.

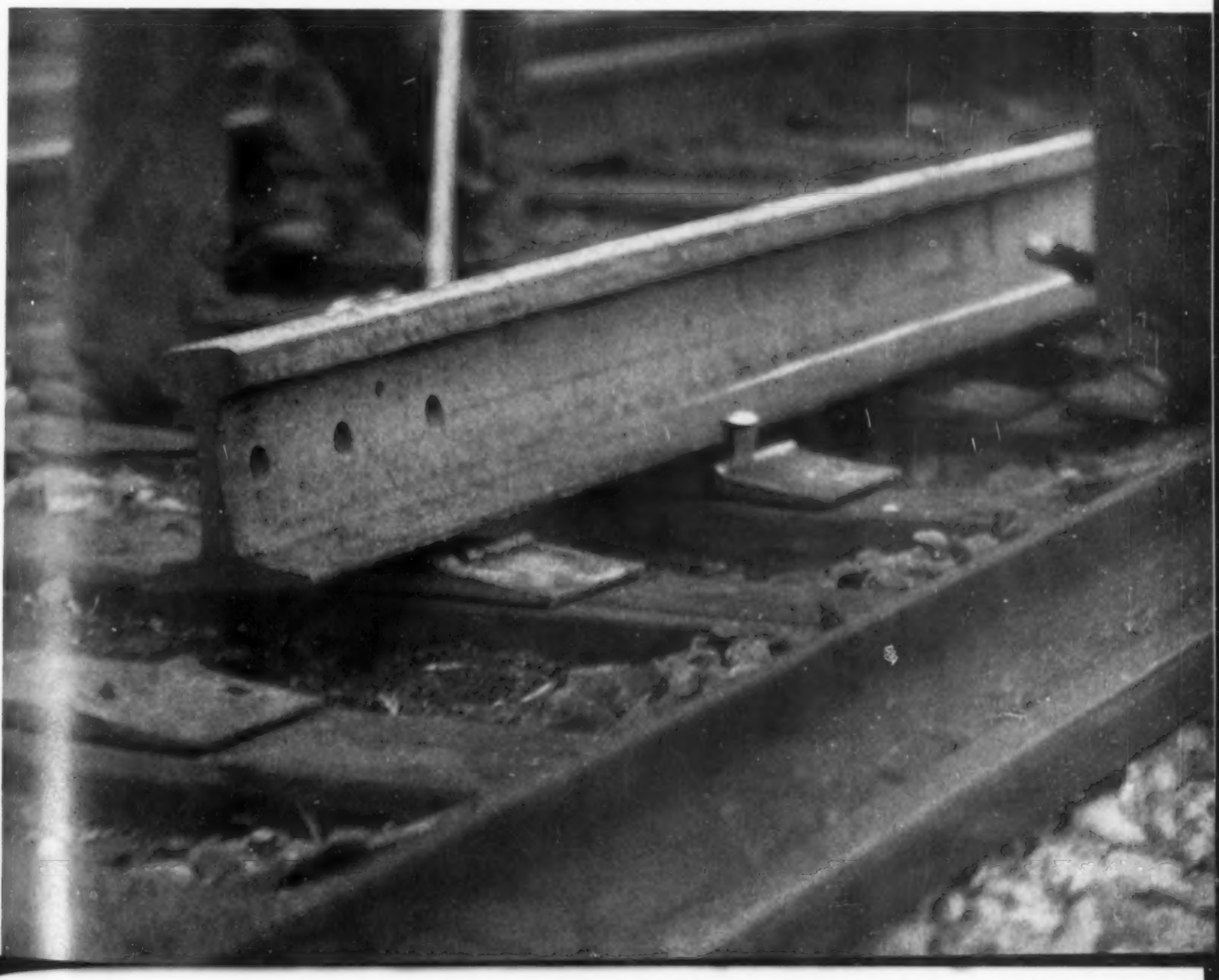
Although tests in the laboratory, made by rolling a heavily loaded wheel over a short length of rail, indicate that wheel loads in excess of 40,000 lb. are necessary to produce typical transverse fissures in shatter-cracked railroad rail, extensive field tests on four railroads carrying heavy travel have shown that from 0.1% to 0.3% of the wheel loads in service actually exceed this value. Therefore, considerable time has been devoted to several possible methods of non-destructive testing that could be used to detect shatter cracks in new rails, and to study-

ing methods of preventing the formation of shatter cracks in the steel during the manufacturing process. However, the numerous electrical, mechanical, and acoustical tests which have been tried have not yielded satisfactory results in differentiating shatter-cracked rails from sound rails. (Such non-destructive tests are designed to measure or detect an increased loss or redistribution of energy produced by the small discontinuities in the steel. Evidently the total amount of energy lost around the microscopic shatter cracks is so small that variations in this energy are masked by variations of energy absorption in the vastly larger masses of sound steel in the rail.)

Since it seems impossible to distinguish between shatter-cracked and sound rails, it is doubly imperative to discover the causes of shatter cracks and a means of correcting these causes. One fruitful theory about the formation of shatter cracks is that hydrogen dissolved in the molten steel tends to escape rapidly from the solidified steel upon fast cooling, collects in certain deep seated regions and develops sufficiently high internal forces to shatter the steel. This, if true, would indicate that slower rates of cooling might allow most of the hydrogen to escape to the outside air gradually at the higher temperatures, and a steel completely free from shatter cracks could be obtained under conditions of slow cooling. Controlled cooling (suggested seriously at least 13 years ago) now seems to offer the simplest solution of the problem of preventing cracking, and further experiments made to determine the optimum practical cooling conditions for rails have shown that appropriate rates of cooling can be maintained in commercial practice.

Though hydrogen may not be the only cause contributing to the formation of cracks, shatter cracks or flakes have been produced in sound steel by hydrogen treatment. It has been found, for instance, that treating an ingot by bubbling hydrogen through the molten steel is a very effective means of insuring a large number of shatter cracks in rails cooled on a hot bed. Hence, the controlled cooling tests were made on ingots treated with hyrogen on the assumption that a cooling process which will prevent the very severe cracking found in

152-Lb. Rail in Pennsylvania Railroad Track. (Photograph by P. L. Mahaffey.)



air-cooled hydrogen-treated rails will also be effective in preventing shatter cracks in rails produced from normal steel. Surprisingly enough, shatter cracks actually *form* at or below a temperature of 300° F., but the rate of cooling at temperatures *above* that range determines whether the cracks occur.

In the normal operation of most of the commercial processes installed in the steel mills for controlled cooling, no evidence of shatter cracks has been found for rails placed in the insulated cooling containers at temperatures of 700° F. or higher, provided the fastest cooling rail did not cool from 700° to 300° F. in less than 7 hr. As an aid to hastening the cooling process to room temperature, the lid may be removed from the container 12 hr. after it has been put in place, and the rails will not develop shatter cracks if the conditions of slow cooling at the higher temperatures are fulfilled. It has also been found possible to prevent cracking of hydrogen-treated rails by holding the steel at temperatures of 1100° F. for 3 hr., or at 900° F. for 4 hr., which, even though followed by fast cooling to freezing temperatures, does not produce internal cracks.

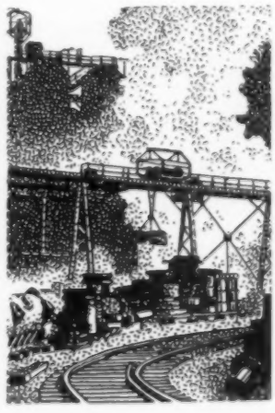
An indication of the commercial value of controlled cooling of rails is given by the fact that of 3,000,000 tons of controlled-cooled rail in service, only three transverse fissures and one split head have been reported. (In 1929, W. C. CUSHING of the Pennsylvania Railroad estimated that there had been one transverse fissure failure to every 3300 rails in service. On that basis, the 3,000,000 tons recently made should have contained about 1300 fissures—certainly enough to have given unmistakable evidence of their presence.) Of these four failures actually reported, three were found to have started at large slag inclusions and the fourth at a blow-hole in the head of the rail. All four of these defective rails were free from shatter cracks.

Consequently, controlled cooling so far seems to be a very effective inhibitor of shatter cracks and may be expected to reduce very greatly the number of transverse fissure failures per year, as the ratio of controlled-cooled rail to total rail in service increases. Nevertheless, controlled cooling will obviously not prevent failures starting from wheel burns or metallurgical defects such as slivers and slag inclusions in the rail.

The mechanical properties of rail steel, both in the hot-rolled and heat treated condition, have received considerable attention not only in relation to the great reduction in fatigue strength caused by the presence of shatter cracks but to the practice of end-hardening rails to resist batter. Above a Rockwell hardness of C-48 to 52, a very abrupt drop in strength, ductility, and toughness of the end-hardened rail steel occurs, whereas rolling load and service tests indicate that hardnesses below Rockwell C-35 result in excessive wear and batter. Briefly, then, the limits of hardness for commercial hardening treatments seem to be set on the high side at C-45 (Brinell 415) by toughness considerations, and on the low side at C-35 (Brinell 320) by batter and wear considerations.

It is encouraging to find that the heat treatment of rail steel produces two beneficial results, namely: Strength and toughness are much improved over those of the as-rolled steel, and the harmful effects produced on the mechanical properties of the steel by a drop of temperature from +70° F. to −70° F. are much smaller for the heat treated than for the hot-rolled rail. Similarly, the properly end-hardened steel has better toughness properties to resist rolling and cold working, both at room temperatures and at low temperatures, than does the as-rolled steel.

In formulating standards for acceptance tests of rails, the slow bend test of a beam with the rail head in tension yields more definite indications of the strength, ductility and energy absorbing capacity of a rail than the old standard drop test. Arrangements have therefore been made for the test party at the University of Illinois to make a further comparison of these two types of test and to draw up a set of detailed specifications for a standard bend test. A set of standard specifications is also being formulated for the proper times, temperatures, and details of practice to be followed in the controlled-cooling process for the prevention of shatter cracks.



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BELL TELEPHONE SYSTEM

PERSONALS

Earle W. Gard is in charge of process and engineering design, Bechtel - McCone - Parsons, Los Angeles.

Eugene F. Ralston is now employed in the openhearth metallurgical department, Jones & Laughlin Steel Corp., Pittsburgh.

Transferred by Westinghouse Electric & Mfg. Co.: **S. W. Chantler**, from superintendent of Feeder Division, Sharon, Pa., to superintendent of small machining, Canton Ordnance Division.

William W. Heilman has been graduated from Carnegie Institute of Technology, and is now employed by the Electro Metallurgical Co., at Glen Ferris, W. Va., as a technical student.

Called to active duty with the U. S. Army: 2nd Lieut. **Edward C. Bergen**, assigned to 723rd Ordnance Company, attached to G. H. Q. Air Force, Portland Air Base, Oregon; 1st Lieut. **George H. Thurston**, Battery M, 6th Coast Artillery, Fort Baker, Calif.; 1st Lieut. **Robert H. Edson**, with the 30th Field Artillery Regiment of the 26th F. A. Brigade at Camp Roberts, East Garrison, Calif.; Lieut. **George E. Doremus, Jr.**, stationed at the Quartermaster School in Philadelphia; 2nd Lieut. **G. W. Higgins**, stationed at the Ordnance Replacement Center, Aberdeen Proving Ground, Md.; 1st Lieut. **Arthur L. Sanford**, stationed with 100th Coast Artillery (Anti-Aircraft) at Camp Davis, N. C.; 2nd Lieut. **Morris E. Nicholson**, assigned to Springfield Armory as assistant to works manager and laboratory officer; Lieut. **Frank W. Brey**, with the 678th Ordnance Company, G. H. Q. Air Force.

George A. Johnson has been made assistant superintendent in the Open Hearth Department, Bethlehem Steel Co., Sparrows Point, Md.

Robert S. Sutton has been transferred from the Metallurgical Department of the American Rolling Mill Co. in Butler, Pa., to the Research Laboratories in Middletown, Ohio.

Harry S. Toups, B. S. Louisiana State University, has accepted a position with the Tennessee Coal, Iron & Railroad Co., in the Fairfield (Ala.) Wire Works Division.

Joseph E. Foster, formerly with U. S. Army Ordnance Department, Rock Island Arsenal, is now metallurgist with Western Cartridge Co., East Alton, Ill.

John W. Hamilton is now chief metallurgist with Hindustan Aircraft, Ltd., Bangalore, Southern India.

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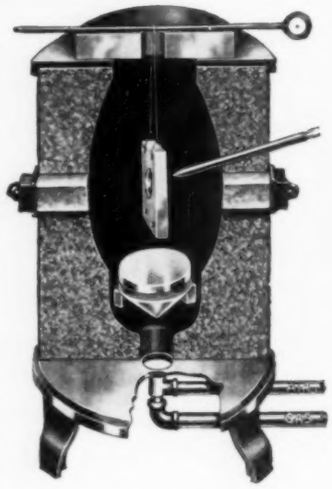

Sectional View of Interoval Furnace, showing method of suspending the work. Note location of deflector and shape of chamber.

INTEROVAL DETAILS

Overall size — 32" high x 20" in diameter.

Heating chamber—14" high, 9" in diameter at center, 7" in diameter at top.

Weight—550 lbs.

This furnace is gas-fired and can be operated at an average cost of 25¢ per hour for fuel. It heats entirely by radiation, the work being absolutely untouched by products of combustion.

Pieces are suspended by wire, eliminating possibility of distortion. Heats to 2350° F. in 40 minutes. Non-oxidizing atmosphere. Two openings at opposite sides of furnace permit localized hardening of tools. Heat resistant tray inserted through openings can be used for hardening small parts. These openings are also used for heating small parts for forging. May be quickly converted into lead, cyanide or salt bath furnace.

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MOLY

PERSONALS

J. Earl Romer, sales staff of Bliss & Laughlin, Inc., has been promoted to district manager of the Cleveland office.

Philip N. Cooke, sales manager of Norton Co. of Canada, Ltd., Hamilton, Ont., has been appointed resident manager.

Joseph F. Oesterle, chairman of the Department of Mining and Metallurgy, University of Wisconsin, is on the staff of the Ladish Drop Forge Co. at Cudahy, Wis., for the summer.

Francis G. Jenkins, formerly in the Materials Standards Department, Eastman Kodak Co., Rochester, N. Y., is now chief, Procurement Section, Watertown Arsenal, Watertown, Mass.

R. P. Newcomb, formerly production manager and metallurgist, Automotive Gear Works, Inc., Richmond, Ind., is now industrial engineer with Jeffrey Mfg. Co., Columbus, Ohio.

C. L. Atkinson, Jr., reserve naval officer employed by Michigan Steel Tube Products Co., has been recalled to active duty as a lieutenant commander serving on U. S. S. Maryland.

William H. C. Webster is now on active duty as 1st lieutenant, Ordnance Department, stationed as Army inspector of ordnance at Pullman-Standard Car Mfg. Co., Butler, Pa.

Transferred by Linde Air Products Co.: **H. T. Herbst**, from the development laboratory at Newark, N. J., to the Los Angeles district as service engineer in the sales department.

Joseph G. Christ is now research engineer at Battelle Memorial Institute, Columbus, Ohio.

Earle R. Saunders received his Ph.D. in metallurgy from University of Cincinnati in June and is now employed on the staff of the development division, Union Carbide & Carbon Co., Niagara Falls, N. Y.

Frank H. Lloyd, formerly with Eastman Kodak Co., has been called for one year's training with Battery H, 209th Coast Artillery, National Guard Regiment, at Camp Stewart, Ga.

Jay Burns is now employed in the new metallurgical laboratory of Goodyear Aircraft Corp., Akron, Ohio.

Raymond B. Smith has resigned as metallurgist in the research department of Republic Steel Corp., Central Alloy District, Canton, Ohio, to accept a position as chief chemist and testing engineer with Reynolds Metals Co., Louisville, Ky.

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• Above is shown the set of 14 broaches used to broach the 90 mm. anti-aircraft gun breech ring. 28 cuts are taken to remove 230 cubic inches of material. One part of the square hole has a 1¼° taper. Squareness, size and taper are held to an accuracy of .0015".

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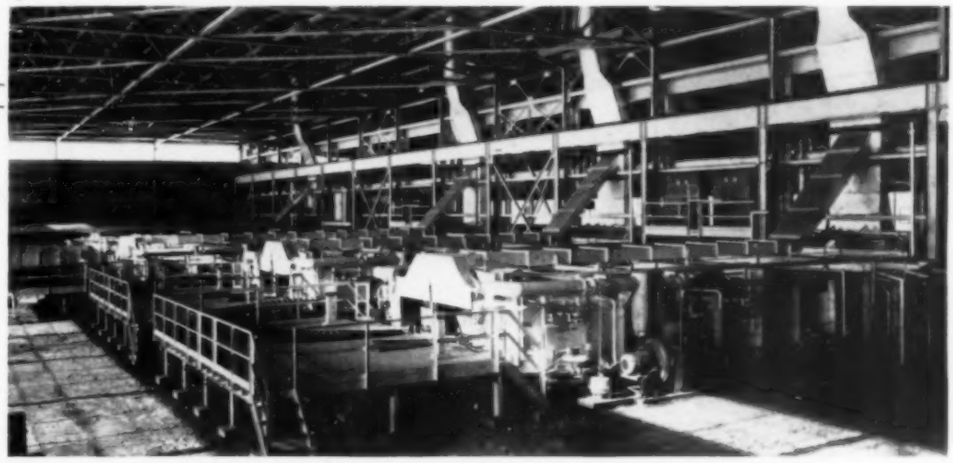

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PERSONALS

Leon R. Jeanneret has been transferred from the Detroit office of the Babcock & Wilcox Tube Co. to Beaver Falls, Pa., as assistant general sales manager.

P. M. Robertson is now associated with the Craig Bit Co., Ltd., of North Bay, Ont., Canada.

Transferred: **Paul M. Tanis** from chemist in the laboratories of Wright Aeronautical Corp. in Paterson, N. J., to the new plant in Lockland, Ohio, as chemist in charge of steel analysis and metal plating control.

Ted B. Krumwied, formerly employed by Die Casting Corp., Glendale, Calif., is now metallurgist for Aero Alloys Co., Vernon, Calif.

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W. E. Jominy, formerly research metallurgist with General Motors Research Laboratories, Detroit, is now associated with the engineering department of Chrysler Corp., Detroit, as metallurgist under direction of F. E. **McCleary**.

Allan L. Brooks is now employed as a metallurgical observer with the Carnegie-Illinois Steel Corp., Gary Works.

Joseph C. Danec has left Battelle Memorial Institute, Columbus, Ohio, and is now in the mechanical section, research laboratories, Norton Abrasive Co., Worcester, Mass.

Philip Johnston has left the Riehle Testing Machine Division of American Machine & Metals, Inc., as district engineer in Hartford, Conn., and is now on active duty as an officer in the Ordnance Department, U. S. Army at Augusta Arsenal, Augusta, Ga.

H. J. Godfrey, engineer of tests, Fritz Engineering Laboratory, Lehigh University, Bethlehem, Pa., has accepted a position as a development engineer in charge of the physical testing laboratory, John A. Roebling's Sons Co., Trenton, N. J.

John G. Sullivan, formerly works metallurgist, Rankin Works, American Steel & Wire Co., Pittsburgh, is now assistant works metallurgist, Donora Works, Donora, Pa.

Albert D. Surtees, formerly with Charles Ogilvy, Ltd., Ottawa, Canada, is now heat treater with Hamilton Gear & Machine Co., Ltd., Toronto.

Victor G. Mooradian, formerly research metallurgist, Division of Industrial Cooperation, Massachusetts Institute of Technology, is now metallurgist in charge of the research and development laboratory, H. A. Wilson Co., Newark, N. J.

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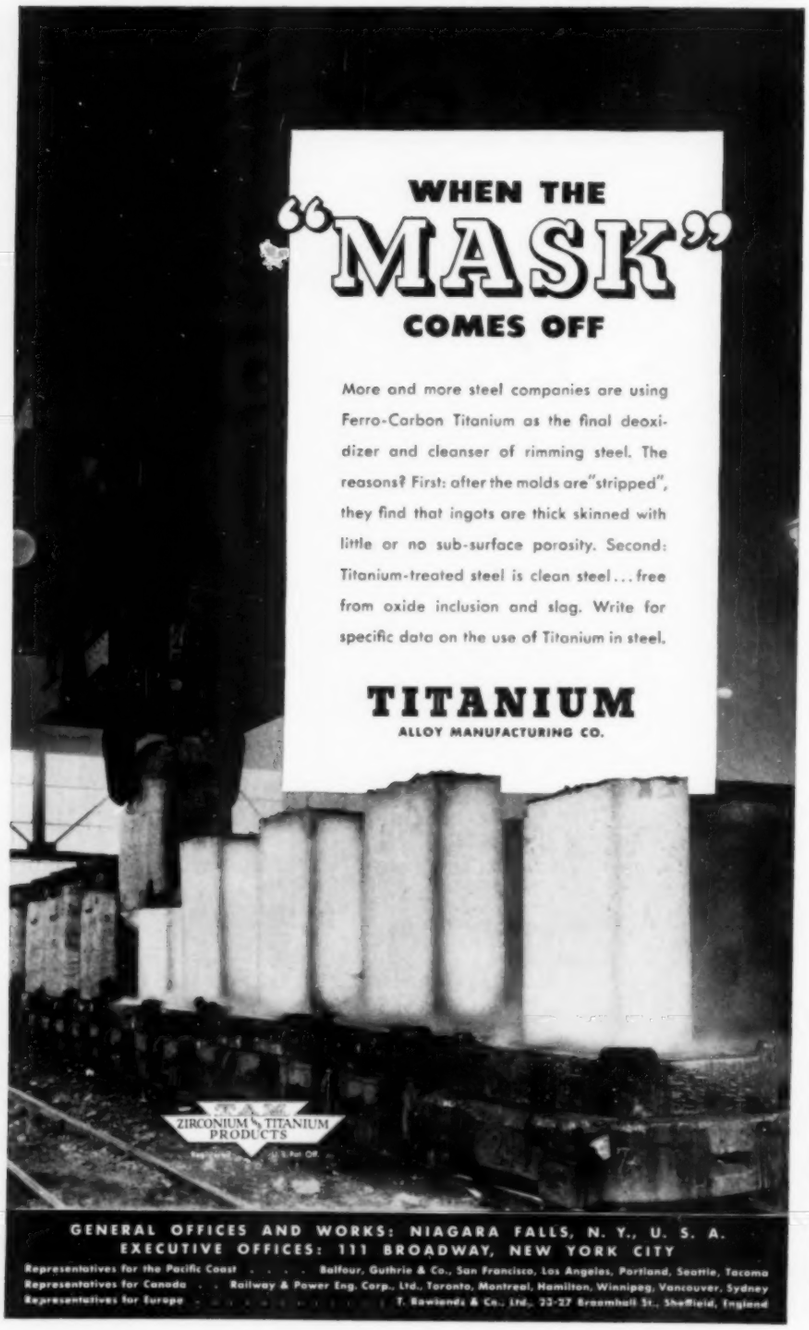
THE new duralumin known in Germany as 681-H is a rivet alloy of the Al-Cu-Mg group which can be worked without previous heat treatment. Since no disturbance of age hardening processes can occur during hammering the shear strength rises by about 2850 psi. as a result of cold working to a minimum shear strength of 34,000 psi. (In the completed structure it is the shear strength of the worked rivet and not that of the original rivet that matters.)

A special type of explosive rivet has also been developed. This contains a hole part way down the axis of the shank, loaded with powder, and the rivet is closed by exploding this charge. Ignition is by electrical means using special tools on the head side. Such rivets can therefore be used in positions which are accessible from one side only. As the introduction of the charge and the actual explosion is only permissible for rivets in the fully aged condition, duralumin 681-H is particularly suitable for this purpose.

The WEIBEL process of fusion welding of light metal sheets is permitting new applications of aluminum forging alloys. From the mechanical point of view it resembles soldering with an electric soldering iron, although the working temperatures are much higher. The process is best suited for welding thin light metal sheets having a thickness between 0.008 and 0.06 in.

Edges of the sheets are usually flanged as for gas welding. The apparatus consists essentially of two carbon electrodes energized by a low frequency alternating current, so the welding heat is generated outside the material to be welded. This process is not resistance welding according to the generally accepted definition — nor arc welding, since no arc is struck with the low voltage of 4 to 8 volts. The material is brought to the melting point by contact with the glowing electrodes and flows into the weld seam much as when gas welding. Mis-fills can be repaired by melting a wire of the same material. In a similar manner sheets over 0.06 in., which cannot be flanged, can be readily welded.

(Continued on page 216)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*"Riveting and Welding of Light Metals; Recent Trends of Development in Germany", by Emil von Rajakowics; *The Metal Industry*, Oct. 27, 1939, page 369.

"Properties of Light-Metal Welds; A Study of the Corrosion Resistance of Welded Aluminum Alloys", by P. Brenner; *The Metal Industry*, Nov. 10, 1939, page 405.

ERY PURPOSE

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Many defense products are being cast today to save time in machining, fitting and assembly. Elaborate assemblies are being reduced to single units, far less costly. Machine and tool builders are using steel castings for many parts because the steel casting is one solid piece of steel cast to exact size.

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Unitcast Corporation, Steel Casting Division
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Dodge Steel Company
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Rochester, New York
The Symington-Gould Corporation
Genesee 101

Tulsa, Oklahoma
Oklahoma Steel Castings Company
1200 N. Peoria. 5-9286

JOINTS IN LIGHT METAL

(Continued from page 210)

Besides the normal butt welding, very clean corner welds are also easily made by this process as well as thin tubes and tube joints. Longitudinal seams in tubes are preferably executed as a flange weld, while for circumferential seams a filler rod is used. The welding of long seams presents no real difficulties after a little practice.

Only the underside of the sheets should be spread with flux, and this should be applied as thinly as possible. Consumption of flux is less than with gas welding, and the quality of the flux may also be lower. The non-hygroscopic fluxes, which normally may not be used with aluminum alloys of high magnesium content, can be employed with the WEIBEL process. This represents an appreciable advantage in those instances where the flux residues cannot be removed. The problem of finding the most suitable electrode is not yet entirely solved.

The shape of the seam, whether pointed or flat, depends largely upon the position of the electrodes and the shape of the electrodes. By using higher currents a correspondingly greater welding speed is possible, although this requires more skill. A secondary run can, after some practice, be made to change the shape of the seam.

Tests have given good strengths for welds in the aluminum forging alloys, particularly to the more heat-sensitive alloys such as duralumin on account of the rapid local heating.

The process, especially suitable for forging alloys, should have wide application in fuselage and wing construction.

BRENNER has conducted corrosion tests on gas welded sheets 1.5 mm. thick of the principal aluminum alloys. The type of weld chosen was the gas welded butt weld. The test method adopted was the German standard immersion test using a stirred 3% sodium chloride solution containing 0.1% H_2O_2.

The greatest resistance to corrosion was exhibited by pure aluminum (99.8%), Mangal (Al-Mn) and KS-Seewasser (Al-Mg-Mn), both in the welded and unwelded condition. All samples of these materials withstood the two-year test without loss of strength, nor could any outward changes in the samples be observed. Test pieces of KS-Seewasser, for example, reveal no difference between the welded and unwelded samples. Hammering of the welded seam also

(Continued on page 218)

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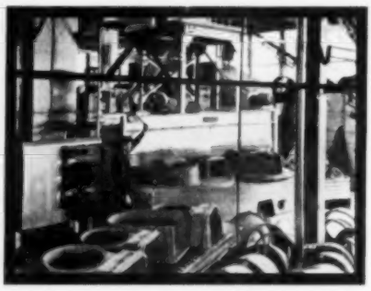

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JOINTS IN LIGHT METAL

(Starts on page 210)

failed to diminish the corrosion resistance. These results are surprising, because it is anticipated that the electrode potential of these materials would be shifted in the electronegative direction by the cold work, so that electrochemical reactions would at least take place between the cold-worked and unworked zones.

The behavior towards corrosive factors of Al-Mg alloys with a high magnesium content is dependent in large measure upon the quantity and character of the Mg_2Al_3 compound separating from the solid solution. Supplementary tempering of the homogenized material at 200 to 400° F. was found to be very deleterious, because the resulting finely distributed grain boundary precipitates led to serious intercrystalline corrosion. Coarser precipitates are less harmful.

Sheets containing about 7% of magnesium were welded both before and after the solution heat treatment and comparative corrosion tests then carried out. While the unwelded samples exhibited practically unchanged strength after a two-year test period, the strength of the welded samples fell in both cases to approximately the same figure (32,500 psi.).

Metallographic examination reveals the cause of this behavior. In consequence of the heat effect in the vicinity of the welded part, a very considerable solution of the normal constituents occurs in a heterogeneous initial structure, while a separation of solid phases occurs in the samples with homogeneous initial structures. In no sample, however, could any connection be established between the structure liable to corrosion and the corresponding boundary grain precipitates.

Fracture of the samples invariably occurred at the transition from sheet to welded area, where superheated structures could be seen under the microscope. Irrespective of the initial structure, all welded pieces exhibited a tendency in this region to characteristic exfoliations which, with further corrosion, took the form of definite blisters visible on the surface.

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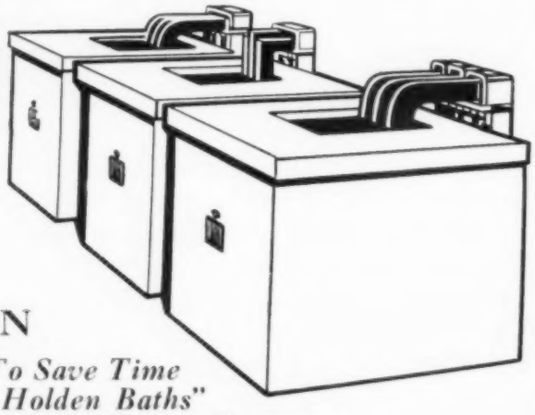

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FORGING—Recommended forging temperature for H-M is between 1900 and 1950 deg. F., after a careful uniform heating and soaking. Large pieces should be thoroughly preheated at 1300-1500 deg. F., before heating more rapidly to forging temperature. Long soaking at forging temperature should be avoided because of decarburization. Decarburization may be retarded by sprinkling borax on the steel when it is at a temperature of approximately 800 deg. F. Use a steel plate to protect the furnace hearth from the corrosive action of the borax. Atmospheric control in the heating furnace will also prove helpful in preventing decarburization.

ANNEALING—Annealing should always follow forging. The recommended practice is to "pack anneal" in coke breeze, cast iron chips, or a mixture of dry silica and pulverized charcoal at about 1500 deg. F., thoroughly soak, and then furnace cool.

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BETHLEHEM STEEL

(Continued from page 186)

tional amount of carbon monoxide in the gas mixture in equilibrium, will decrease. Consequently, an atmosphere generated as stated in the article by Messrs. SLOWTER and GONSER will carburize a steel whose position on the iron-carbon diagram is to the left of the graphite line, if sufficient time is allowed.

The practical proof is to place the steel directly in the hot charcoal. Since the gas produced is at equilibrium with carbon, it has the same carburizing power to the steel as the carbon itself. In short, the gas is equivalent to energized carburizing compound. It is, of course, a commonplace that steel will be carburized by carbon at the same temperature.

If the heating cycle is short as, for example, in hardening, sufficient time for carburization may not be allowed. The problem then becomes one of rates. In such a use, this atmosphere will be very satisfactory for the reasons stated in the article.

LLOYD B. KRAMER
Metallurgist
Union Drawn Steel Division
Republic Steel Corp.

Mr. Gonser Replies

We are in agreement with Mr. KRAMER's statements and agree that steels unsaturated with carbon may be carburized by the atmosphere under discussion if exposed to it for a sufficient time. However, we believe that the text of our article is equally correct and that Mr. KRAMER has misinterpreted it.

It should be noted that in the sentence which he quotes, above, we only stated that the atmosphere was non-decarburizing but we did not say that it was non-carburizing. Further, at the top of page 563 we stated,

"Since this atmosphere depends for its effective operation upon the fact that an atmosphere in equilibrium with carbon will also be at equilibrium with a steel (that is, neither decarburizing nor oxidizing) . . . ."

These statements, we believe, show the point which we were then emphasizing, *i. e.*, that the atmosphere was non-decarburizing. Nowhere in our article do we find a statement which implies that the atmosphere will not carburize under certain conditions and this appears to be the point which Mr. KRAMER brings up.

We emphasized non-decarburization since this is usually an important feature of an atmosphere for hardening operations. Carburization is usually not so serious a problem under these conditions, although it may sometimes be important.

BRUCE W. GONSER
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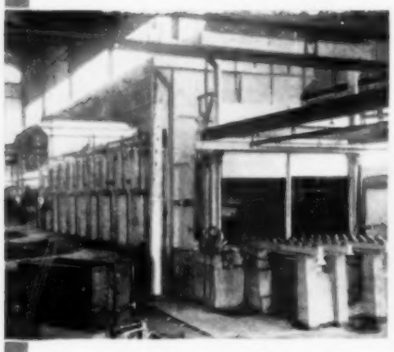

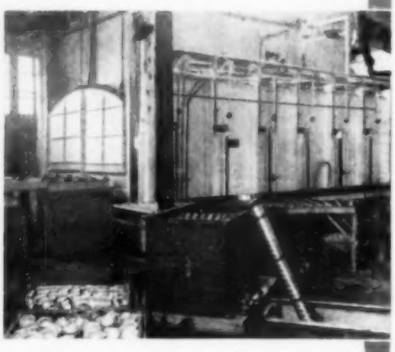

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MONEL METAL

(Continued from page 197)

The time within the furnace will depend on the time-temperature curve recorded by the thermocouple in the charge, and, of course, is regulated by the softening effect intended, as discussed in earlier paragraphs.

After annealing, the box may be cooled in the furnace or may be withdrawn and cooled more rapidly in the air. Care should be taken to increase the flow of reducing gas so as to maintain the 0.2-in. pressure within the box, or the 1 to 2-in. flame length, whichever means of regulation is being used. When the box has cooled to below 500° F. there will be no danger of oxidation and the charge then may be removed. However, it will usually be found just as convenient to allow the box to cool completely, so that it can be opened by hand.

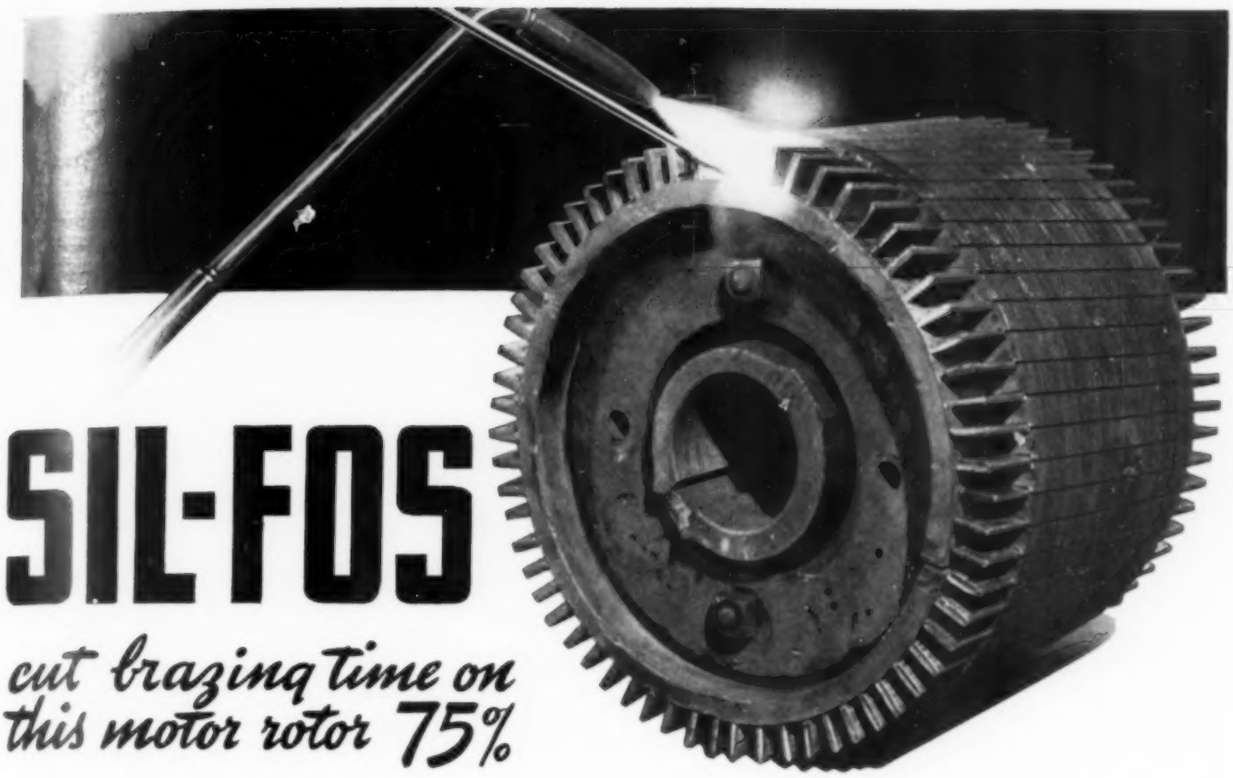
Cooling

Neither slow cooling, whether in or out of the furnace, nor quenching, has any effect on the softness of annealed Monel or "R" Monel ("K" Monel is a hardenable alloy, so this statement does not apply.) Frequently, therefore, the metal is quenched to economize time, and (if not bright annealed) to minimize oxidation. If facilities are available the high nickel alloys may be quenched in a 2% solution of denatured alcohol. This will reduce the "oxide flash" formed by the oxygen of the air during the transfer from the furnace to the quenching tank. When heated in reducing atmospheres and quenched quickly, the surfaces of nickel and Monel will be silvery white. A gray tint on nickel and a pink color on Monel indicate either oxygen in the furnace atmosphere or delay in quenching.

It is advisable to test the furnace atmosphere first. If the pink flash is obtained with Monel, the air supply should be reduced and any leakage of air into the furnace prevented.

When quenching is inconvenient, the work may be air-cooled. The oxide formed thereby is extremely thin, glossy and tightly adherent. Light rubbing with No. 00 emery cloth will remove it readily.

The chromium oxide formed on Inconel cannot be reduced by quenching in alcohol. It can be removed best by pickling.



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SOFT METAL

(Continued from page 171)

Many attempts have been made to explain the outstanding difficulties offered by the softness of the single crystals — their proneness to glide under very small shear stresses. The atoms are bound in their places by interatomic forces, the potential of the field of force having a minimum at the position where the atom is in equilibrium. If an atom is moved from this position the force tends to restore it; the case is similar to that of a table covered with a regular network of depressions, with a ball lying in each depression. Now consider the force required to move *all* the balls at once in a given direction, so that each rises out of its hole and falls into the next hole in that direction. It will clearly be the force required to move a single ball multiplied by the number of balls, and this is equally true when a ball lies in every hole and when a few vacant holes exist in the array.

From this simple illustration it is seen that the low value of the critical shear stress cannot be accounted for on the basis of the simultaneous movement of all atoms in a glide plane.

The position may perhaps be clarified by considering simply a row of cylinders touching one another, with a second row of cylinders resting on them, as in the model illustrated on page 171. The force required to move one whole row over the other is considerable. Suppose, however, that the number of cylinders in the upper row is one or two fewer than that in the lower row. In the model a place of non-fit (a "dislocation") is arranged at one end of the row, toward the right, there being four in the upper row to five in the lower row here. To make the model resemble the atomic case better, all the upper cylinders in the model are connected to a long strip of elastic band. If we now run our hand over the upper row, from right to left, which is equivalent to imposing a force from left to right on the lower row, it is easy to make this dislocation travel along. At any given moment we are only moving a few cylinders through the periodic field of gravitational potential. After the dislocation has traveled from end to end, however, every cylinder has moved one place, and the whole row is displaced relatively to that below, although at any given moment we were only moving a few cylinders.

The fact that glide takes place at shear stresses so far below the theoretical value shows that a whole sheet of atoms cannot travel at once over a neighboring sheet. Under shear the whole crystal plane does not move by one atomic spacing simultaneously; rather the misfit runs easily through the crystal, leaving in its wake atoms properly spaced. In a sense, then, the weakness of the single crystal is due to imperfections which are

(Continued on page 237)

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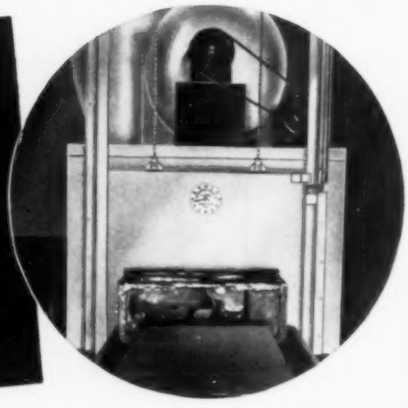

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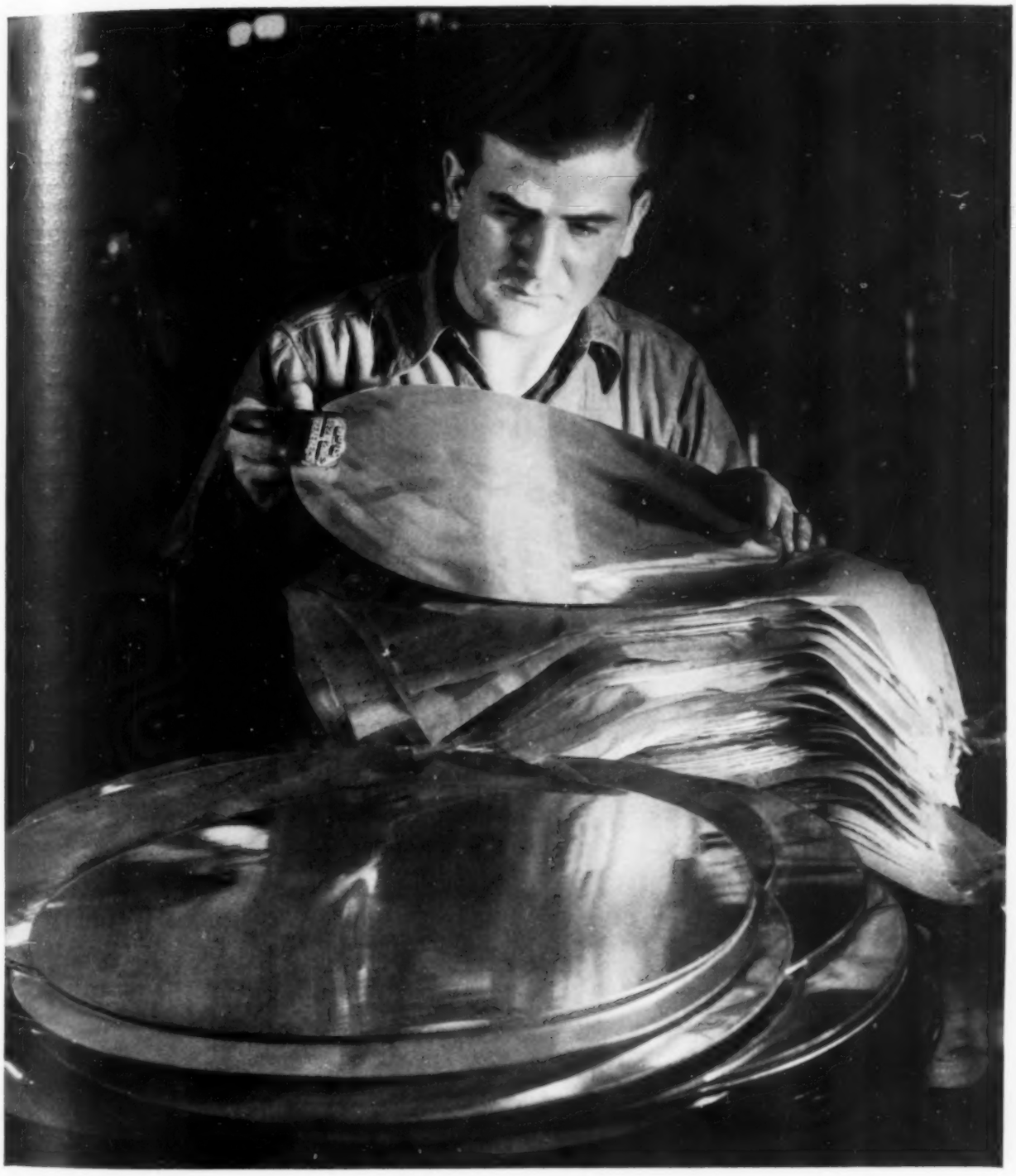

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SOFT METAL

(Starts on page 171)

somehow inherent in the structure. A perfect crystal might have theoretical strength, but probably no such thing exists.

There is considerable doubt and diversity of opinion as to the origin and end of the dislocations. I have not time to discuss the details and difficulties; the general conception of a traveling misfit seems, however, to be undoubtedly the proper basis for any theory of glide.

Another fruitful conception is that of cracks, notches, or other regions of local peculiarity leading to increased local stress. Thinking of a wooden plant, we may perhaps be allowed to call these hypothetical regions "knots". Certain mathematical deductions can be made from the assumptions that the regions of stress concentration are very small, and that the stresses depend on the irregularities of atomic motion in the neighborhood. Every now and then the atoms so will dispose themselves that, speaking loosely, the crack is "sharper"; the longer one waits the greater the chance that the local stress due to atomic vibrations reaches some high critical value. The rate of flow of a crystal under stress will then be proportional to the frequency with which the critical stress is reached at the local "knots".

The resulting mathematical formula shows that flow should take place at any stress, but if the stress is below a certain value the flow is unobservably small. This is the kind of thing we must expect to find in theories based upon probabilities.

If this view is correct, we cannot define a critical shear stress for a single crystal by saying it is the resolved shear stress at which glide begins to take place, for this will depend upon what rate we are prepared to consider noticeable. Experiments on pure cadmium verify these conclusions as follows: A stress of 5 g. per sq.mm. produced a flow of 1% in 13 days; 10 g. caused 1% flow in 7 hr.; 13 g. in 1 hr.; and 15 g. a flow of 1% in 13 min.

It is well known that shear movements (slip, or plastic flow in metals) cause a hardening action, and this is usually expressed by curves where shear stress is plotted against extension. Interpretation of these curves is difficult, however, because the above described time element is not taken into account. By working within a region where the rate of flow is very small, and applying the stress fairly rapidly, hardening curves with some meaning can be obtained, but attention has not always been given to this point.

The time element being eliminated as best one can, curves showing the variation of stress with glide at temperatures suitably chosen can be obtained. Some very striking results are available on metals of compara-

(Continued on page 241)

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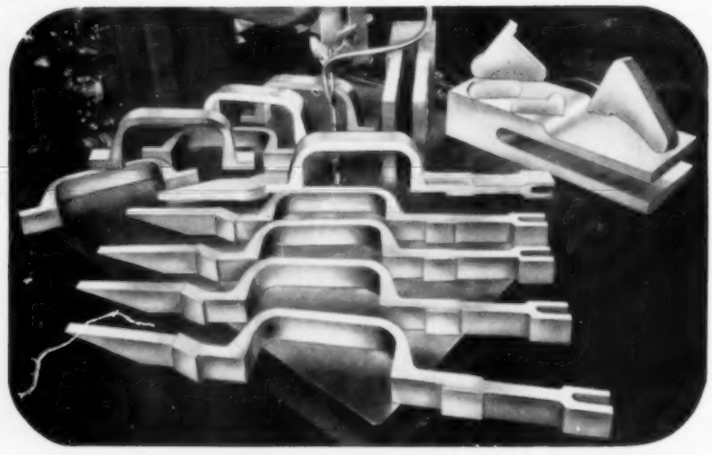

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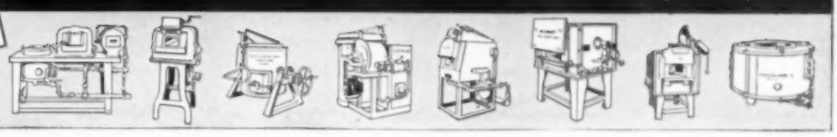

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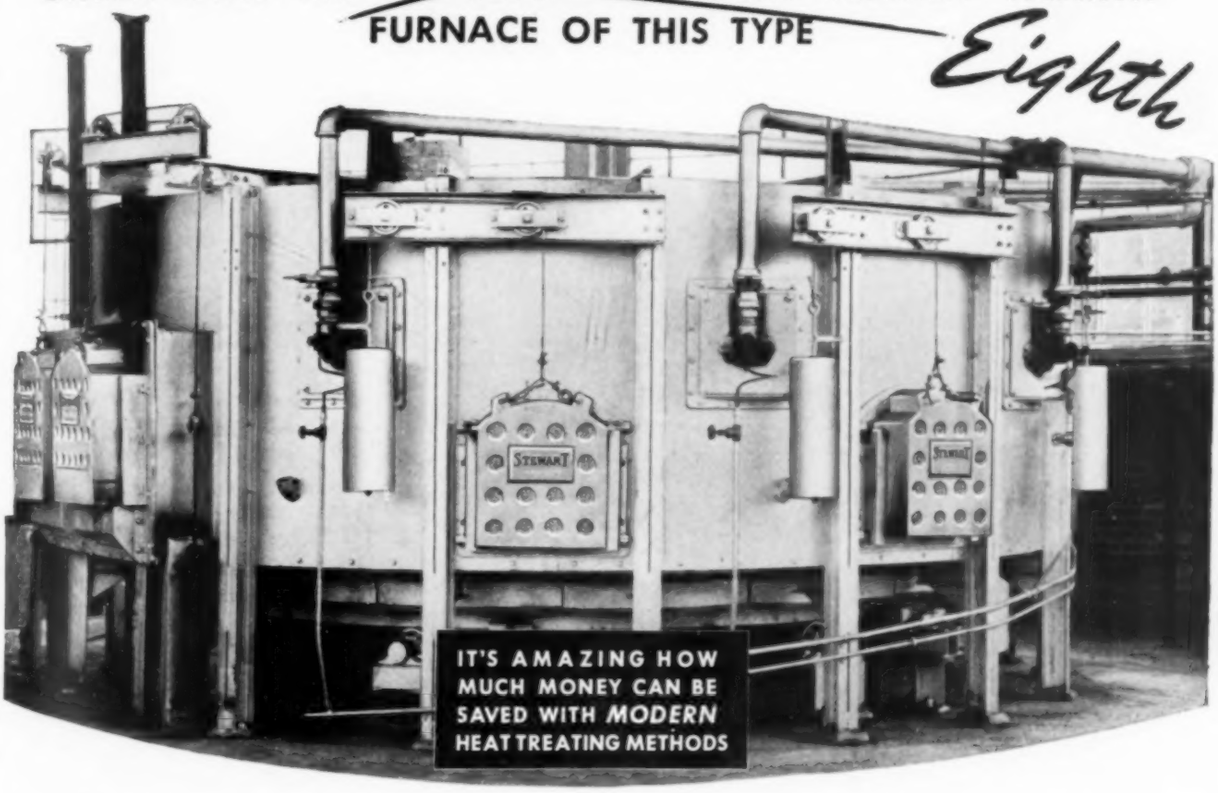

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SOFT METAL

(Starts on page 171)

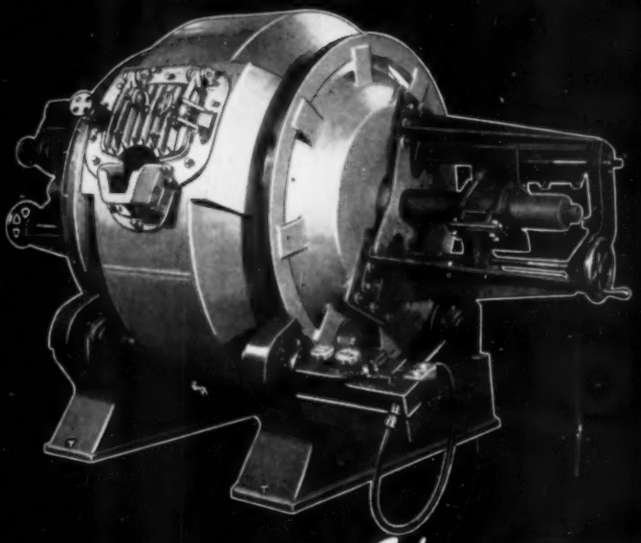
tively high melting point. With a single crystal of nickel a shear strain of 30% produces an increase of shear strength of 14 times; with copper a shear strain of 67% produces an increase of strength of 68 times; while with silver a shear strain of 95% produces an increase of strength of 92 times, all at atmospheric temperature.

We have now to consider how this hardening under strain comes about, and here X-rays furnish a valuable indication. By their use we determine that the unstressed single crystal becomes an agglomeration of small units, slightly rotated and dislocated in orientation during plastic flow. I think that there is now definite evidence that the strengthening is largely due to the break-up of the crystal, to a loss of its single-crystal character. Much more experiment is, however, needed to clear up the situation.

This brings us to polycrystalline metal, and this is the metal of every-day use. Why is it stronger than the single crystal (even though much weaker than the theoretical crystal)? On the whole it looks as if small grain size is favorable for strength. During plastic deformation slip takes place in the individual crystallites, whose axes are differently oriented. In some way the boundaries between the crystallites must confer strength, but they cannot do it because they are inherently strong — the number of atoms involved is too small. Expressed in another way, the crystal boundaries cannot be regarded as playing the part of the expanded metal in reinforced concrete. They are too thin, whatever reasonable strength may be attributed to them.

Supposing that, to account for their weakness (low yield point) as compared with ideal crystals, we accept the hypothesis that the crystallites contain submicroscopic flaws where the stress concentration is abnormally high. If a dislocation runs from such a crack it will travel as far as a crystal boundary and will then find, for a region a few atoms thick, at any rate, a place where the regularity necessary for it to propagate itself is lacking; it loses itself, but not because the boundary is hard as assumed by some metallurgists — rather because it is *soft!* (The theoretical weakening effect of a crevasse is based upon a postulated rigid behavior of the solid; if the solid yields plastically, the local stress is dissipated and the tearing does not take place.)

There is no doubt that the intercrystalline boundaries play a very important part in the strength of metals. However, the experimental study of the properties of these boundaries is only just beginning, and much work with different metals and at different temperatures is required before we will have enough data to found a comprehensive theory.



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